

FISH AND GAME COMMISSION OF CALIFORNIA

FISH BULLETIN No. 11

THE CALIFORNIA SARDINE



By the
STAFF OF THE CALIFORNIA STATE
FISHERIES LABORATORY

Contributions Nos. 52-56 from the California State Fisheries Laboratory.



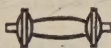
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FOREWORD.

These papers are the first of a proposed series describing initial results of the attempt of the California Fish and Game Commission to establish a logical and adequate system of observation of the important fisheries of the state. In pursuance of this attempt, under the direction of Mr. N. B. Scofield, a laboratory has been built at San Pedro, a system of statistics has been inaugurated, and considerable scientific research has already been done.

Of the authors of these papers, but one, W. L. Scofield, now remains in the employ of the state. The papers have all been finished after the departure of the authors, and as each of them has been engaged in other duties, some delay in publication has arisen.

W. F. THOMPSON.

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THE CALIFORNIA SARDINE AND THE STUDY OF THE AVAILABLE SUPPLY

By

WILL F. THOMPSON.

This paper is No. I of a series published by the Fish and Game Commission of California in Fish Bulletin No. 11, and is Contribution No. 52 from the California State Fisheries Laboratory. It was submitted for publication virtually in the present form early in 1925.

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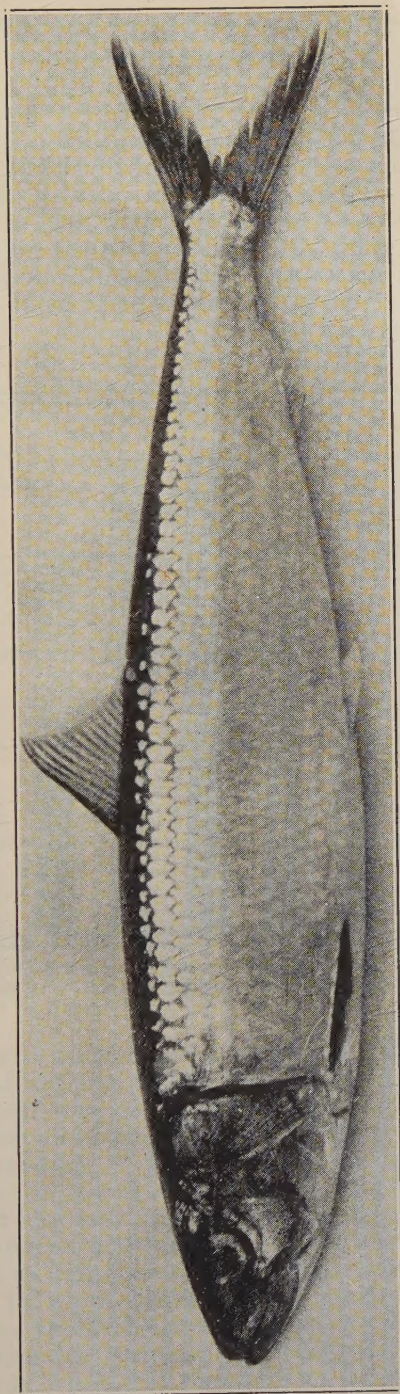


FIGURE 1. Photograph of San Pedro Sardine.

THE CALIFORNIA SARDINE AND THE STUDY OF THE AVAILABLE SUPPLY.

By WILL F. THOMPSON.

There has been a truly marvelous development of the sardine fishery in California. Although it originated as a great fishery during the stress of war, the industry has shown a vitality which augurs well for its permanence so long as the raw material is obtainable. The amount caught exceeds by far that taken of any other species in California, and there appears at present no other which is capable of the tremendous yield, unless it be the unused anchovy.

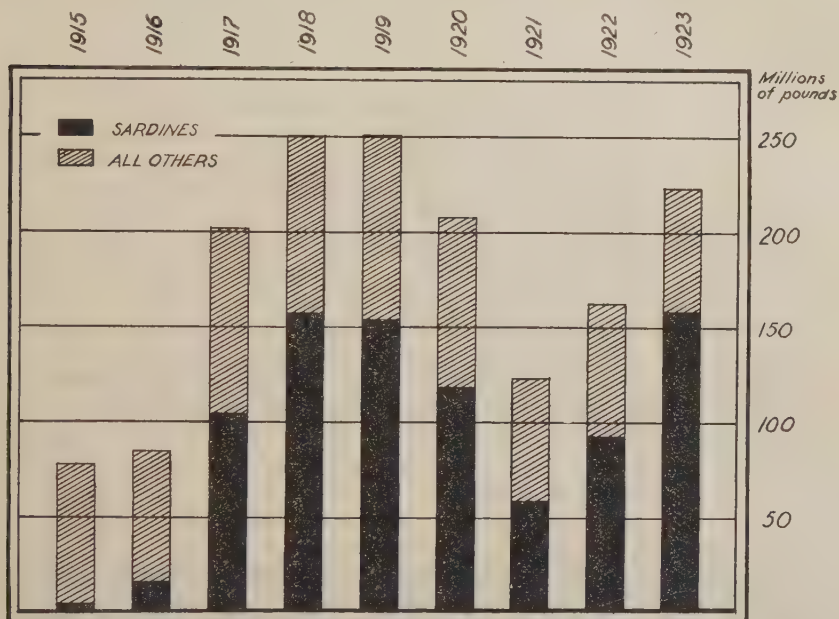


FIGURE 2. Catch of sardines in California, compared to that of all fish. Data from California Fish and Game Commission, save for 1915, which is from the United States Bureau of Fisheries.

Experience with older fisheries has shown that rational use demands a knowledge of at least two things. There must, above all else, be information from time to time regarding the manner in which the species is withstanding the strain of the fishery. But there must also be an understanding of the natural changes in abundance which inevitably occur, so that these may be distinguished from the effects of overfishing and also may be foretold and understood. Based on such knowledge regulation and exploitation may be rational and restrained.

To this end we must concern ourselves principally with the commercial catch, in which lies mankind's major interest. In so doing we meet at once the problem of accurately recording that catch and then of analyzing the complex underlying the biologic and economic conditions. It is hoped that the program which has been adopted for this purpose by the State of California will prove by further experience to be sound and to lead far.

Begun as a simple introduction, this paper was at first intended merely to give the background of our investigations. It has been expanded to include a discussion of several things fundamentally important to our purposes, and this discussion portrays rather imperfectly the viewpoint acquired by actual experience with the Pacific sardine. The investigation has, indeed, molded and directed our first ideas and methods.

The purposes of the investigation were the seemingly simple ones of detecting depletion caused by overfishing and of following the great natural changes—which might be foretold were our work extensive and precise enough. The complexity of the problem has become increasingly apparent, and has necessitated a careful consideration as to what our sampling really consists of. As this sampling is the proposed basis for a necessarily long continued program of observation, it deserves careful analysis.

When, in attacking our problems, we sought for aid from the existing literature on the European sardine, there were found plain evidences of the same complexity in the phenomena attending the fishery for that species. This complexity we regard as indicating the necessity for the type of program adopted.

And in making use of what information existed as regards this European species, we have found it necessary to define somewhat closely the real relationships of the California and European sardines. The constant comparison that is inevitable should rest on a sound foundation.

It would seem, incidentally, that the degree of relationship in habits might correspond roughly to the degree of relationship in structure. But as to the truth of such a surmise little can be said at present, since sufficient knowledge of habits is lacking in both species. Perhaps the advance of science will change this situation.

I. Morphological Comparison with the European Sardine and its Races.

A study of the literature on the European sardine, more particularly that of the French Atlantic coast, gives ground for apprehension, for great natural changes in the yield other than those due to overfishing have at times nearly destroyed the dependent industry. But there is, at the same time, no evidence to be derived from a knowledge of the European form upon which opinion as to its resistance or that of our own sardine to overfishing may be soundly based.

There are, nevertheless, several reasons why the European sardine should take a prominent place in any discussion of the California species. The fishery for it is one of the oldest and best known, and it competes in the market with the Pacific species. Furthermore, it is the only closely related form which has been investigated to any extent scientifically. Experience has, indeed, shown us that ideas regarding the European species, the variability and permanence of the supply, are apt to be applied rather freely, not merely in ordinary conversation but in courts of law. As we shall see, the species are in fact closely enough related to lend some validity to general comparisons, and to conclusions regarding the character of the necessary investiga-

tions, but are nevertheless sufficiently distinct to invalidate direct transference of ideas as to particular habits, growth, etc.

The writer has, fortunately, been able to obtain a series of the European sardine (or pilchard) from Plymouth,¹ England, and another from St. Jean de Luz, France, for direct comparison, through the good offices of the Federal Bureau of Fisheries, there being available otherwise a single specimen in the collection of Stanford University, and five specimens kindly forwarded by Mr. Perry Clark of the U. S. Bureau of Chemistry. The latter five were not in the best state of preservation when received from Douarnenez, France.

The true sardine, or pilchard, is found from England along the Atlantic coast of Europe southward into the Mediterranean, and the adjacent coasts of Africa. It has been divided into two races, or varieties, the one found in the Atlantic and known as *Sardina pilchardus pilchardus*, the other found in the Mediterranean and known as *Sardina pilchardus sardina*. It still remains to be carefully investigated whether the difference between these two subspecies, or varieties, or races, is less than exists between some of the other "species" of sardine.

There are, indeed, throughout the world a number of these very closely related species of sardine. Thus, there is the sardine of the Pacific coast of America, from Alaska to Mexico, known as *Sardina cerulea*, and that of the coast of Peru, known as *Sardina sagax*, perhaps belonging to the same species, perhaps not. There is a gap of considerable extent between the extremes of their distributions, namely, the tropical waters of the Gulf of Panama, and careful examination of many specimens will some time be necessary to determine their distinctness. Nevertheless, they both are allied to the sardine or pilchard of Europe, in habits, distribution in the sea waters, movements and structure. They are the only true sardines found in the waters of the Americas, save, perhaps, a species found occasionally in the West Indies, for no sardine is found on our Atlantic coast.

On the other side of the Pacific there are found the Japanese sardine, *Sardina melanosticta*, and the Australian, *Sardina neopilchardus*. These are both very close to the European species. There is also a sardine to be found in the waters of the Cape of Good Hope, known as *Sardina ocellata*. The inter-relationships of these various species are very poorly known and the morphological characters upon which they are based are insufficiently studied.

For the present, *Sardina sagax*, the older name, will be regarded as including *Sardina cerulea* of California. No extensive comparison will be attempted other than that between *Sardina sagax* and *Sardina pilchardus*, the European species.

There are certain well-marked structural differences between the species which may be relied upon to separate the individuals, irrespective of the variability within either species. These are color, scale characters, and the lengths of certain gill rakers.

The European species shows a lack of the dark spots as large as the pupil of the eye, which are usually but not always found along the sides of the California species, *Sardina cerulea*. Smith (1901, p. 3) gives this color difference as a specific one.

¹ From the Laboratory of the Marine Biological Association. Taken off Plymouth on the second of November, 1924, for which we express our thanks to Dr. E. J. Allen.

A second difference, or group of differences, is found in the scales. In *Sardina pilchardus* the exposed sections of scales along the flank, particularly under and behind the dorsal, are alternately large and small, so that the exposed portion of each small scale is overlapped very

Scales.

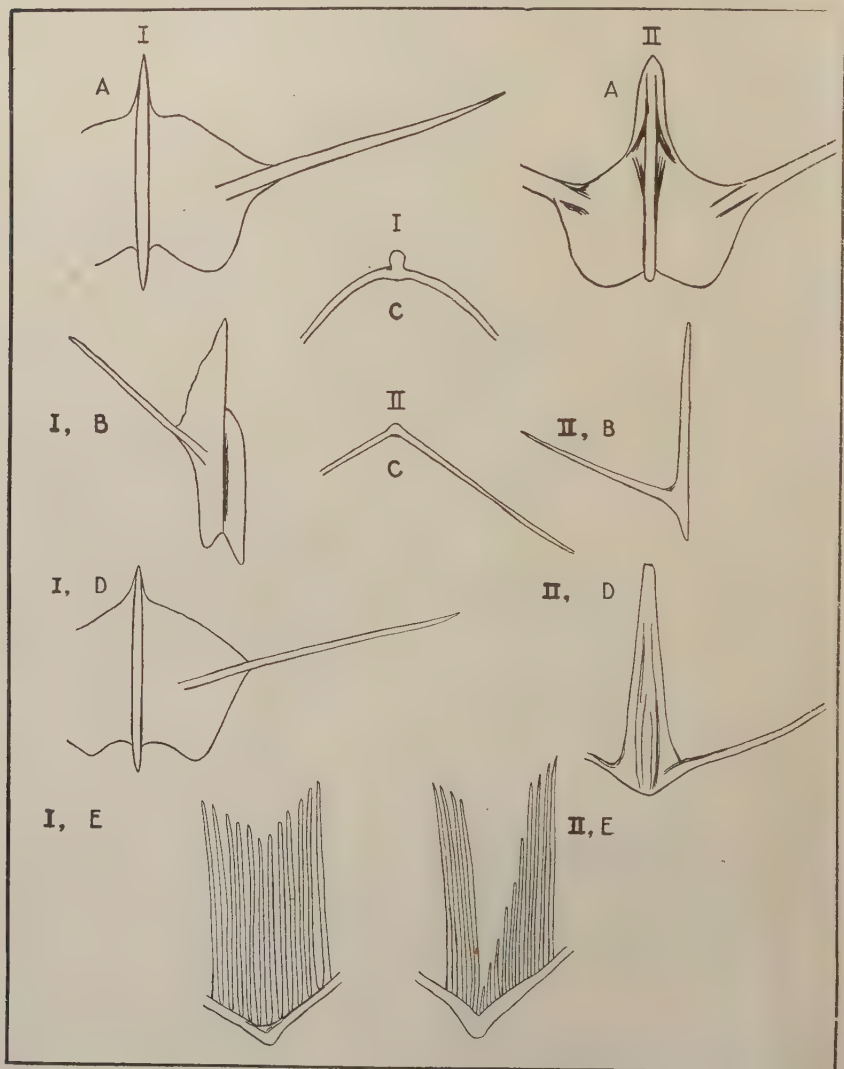


FIGURE 3. Comparison of forms of scales in European and California sardines.

I. European II. California

A. Fifth keel scale anterior to ventral fins, ventral view.

B. Keel scale at tip of ventral fins, lateral view.

C. Same, posterior end view.

D. Same, ventral view.

E. Angle of first gill arch on right side, showing length peculiarities of gill rakers.

nearly completely by that of the next anterior one. The result is an appearance of fewer and larger scales in the European species than

in the Pacific form, whereas, as an actual fact, although differing in average number, they both possess about 55 in a lateral series, as may be shown by counting the scale pockets after removal of the scales. Again, the "serrations" along the ventral edge of the body are much weaker in character in the California sardine, and the scales carrying them differ markedly in shape, especially those which lie at the level of the tip of the ventrals when these are laid along the body. The accompanying plate will illustrate these facts without further descriptions. There may be, of course, further differences of this nature, but examination has thus far failed to show them.

A third difference is found in the gill rakers, of which three or four become markedly shorter in the California sardine at the angle of the first arch, but do not show any signs of so doing in the European. This also is shown in a plate (figure 3, E).

These three well-marked differences could doubtless, on prolonged study, be supplemented by others, but it would appear that they suffice to represent those which seem clear and well defined, and which would not be expected to be greatly variable within the species. In these no Pacific sardine approaches the European individuals examined. They are not differences in organs of major importance, seeming to belong, rather, to the superficial or minor structural characters.

Page (1920, A and B) has given a series of measurements of head length and of the distance of the dorsal insertion from the snout, but due to the unknown differences in methods of measurement used by Page and ourselves, there is little utility in comparing our data with the head lengths and the position of the dorsal given by him.

In table 1² are given measurements of body proportions and counts for thirty English sardines, fifteen French and nine California. These are plotted in figure 4. The presentation of a larger series was not thought worth while, in view of the marked differences in preservation of the several samples, and the changes in measurements, which a slight difference in handling the specimens produced.

As is evident from this table, and from comparison of individuals held in the hand, the head of *Sardina sagax* of California is longer, as is the distance of the tip of the snout from the end of the maxillary (called maxillary length), and as are other head proportions. The difference in head length is emphasized by a more squarely cut posterior edge to the opercle and subopercle in the Pacific species, the length of the head tending at the same time to produce an impression of lesser body depth than is really present.

The interopercle of *Sardina pilchardus* is extremely narrow, being just visible in many cases, while that of *Sardina sagax* is prominent and triangular. The preopercular edge is bowed sharply backward and the ridges on the opercle are very much more vertical than in *Sardina sagax*. In fact, all the opercular bones are different in shape.

The insertion of the dorsal fin is in nearly the same relative position, but the ventral and anal are set further toward the caudal in the California sardine.

²See page 63.

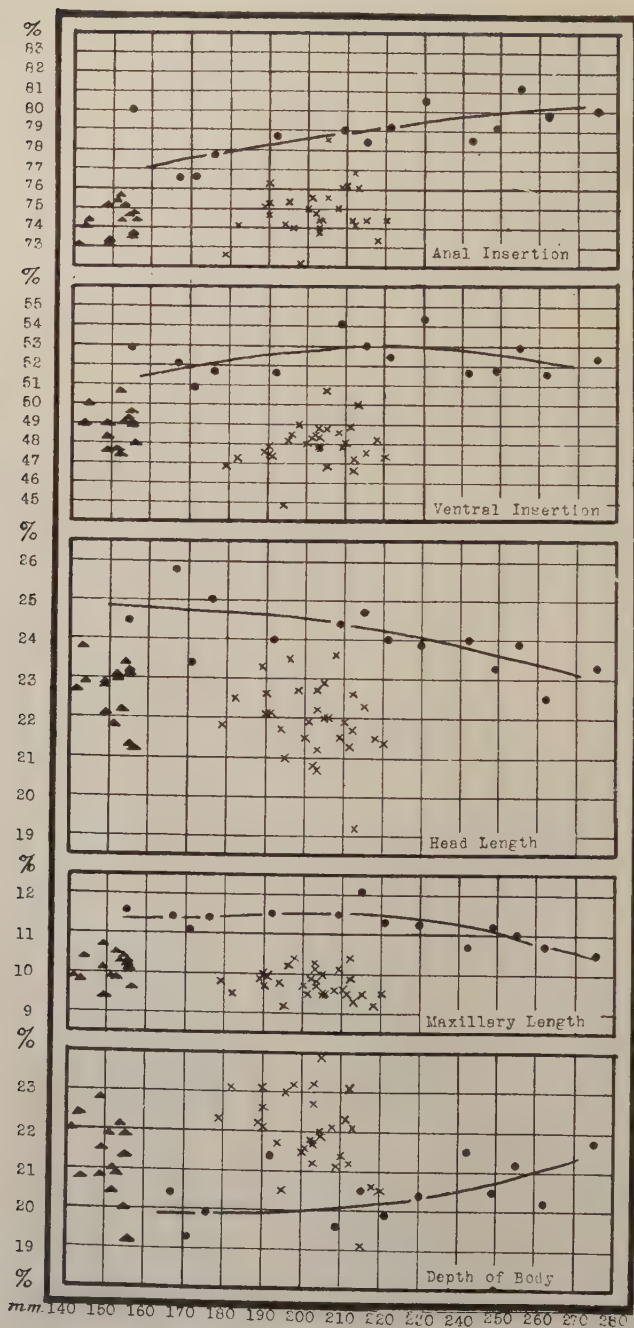


FIGURE 4. Measurements of body proportions, given in percentages of the body length.

Dots—San Pedro sardines.
 Triangles—French sardines.
 Crosses—English sardines.

Taken in conjunction with the peculiar squamation and lack of color of the Atlantic species, this difference in proportions renders the two species markedly different when individuals are compared directly.

As would perhaps be expected of species in the same genus, the vertebral count³ does not vary greatly. In table Meristic Characters. 2, vertebral counts for San Diego, San Pedro and Monterey are given in contrast to those of our specimens from St. Jean de Luz, France, and Plymouth, England.

TABLE 2.—Comparison of vertebral counts of European and California sardines.

No. of vertebrae	San Diego	San Pedro	Monterey	St. Jean de Luz	England
50	6	9			
51	107	113	33	3	9
52	177	181	67	17	28
53	15	14	11	5	14
54					1
Number	305	317	111	25	52
Mean	51.66	51.63	51.80	52.08	52.13
Sigma	0.60	0.62	0.60	0.56	0.71
P. E.	±0.023	±0.023	±0.04	±0.075	±0.07

Combining the localities in either ocean, the mean number of vertebrae of the Pacific series is $51.69 \pm .015$, and that of the Atlantic series $52.12 \pm .051$. The probable difference between the means of two such series would hence be .053, as compared with an actual difference of .430, approximately eight times as great,⁴ therefore significant.

The two averages are hence significantly different, from the standpoint of the calculated probable errors, but judgment should be suspended until the existence of grosser errors is discussed under the heading of local races.

We may present a table⁵ of counts made under the microscope on carefully removed gill rakers of Pacific and Atlantic sardines, using the lower limb of the first arch. They are plotted in a graph in figure 5. There are included in tables 1 and 3 and figure 5 the counts of five specimens from Douarnenez, fifteen from St. Jean de Luz, thirty from England, and others from Japan, Peru and Lower California.

The great increase in number with the increase in body length is noteworthy, and the counts from European specimens are very distinctly less, size for size.

³ The vertebral counts upon Pacific sardines presented in this paper were made by W. L. Scofield for Monterey, and G. W. Hunt for San Pedro and San Diego. The skeletons prepared for this purpose are stored in this Laboratory. The two series from Europe were counted twice by W. L. Scofield and checked by W. F. Thompson, from skeletons prepared by Wm. C. Herrington. The hypural is included in all counts made. (See also Hubbs, 1925.)

⁴ Probable error of mean = $\pm .6745 \frac{\text{Sigma}}{\sqrt{n}}$

Probable difference between means = $.6745 \sqrt{\frac{\text{Sigma}_1^2}{n_1} + \frac{\text{Sigma}_2^2}{n_2}}$

where "sigma" is the standard deviation of the series of counts, and "n" is the number of counts.

⁵ See table 3, page 64.

The presence of local races in the European sardine is of interest from the standpoint of the validity of some of the above mentioned specific differences and from that of what may

Local Races.

be expected in the Pacific. No attempt will be made to review in a thorough way the work of Fage (1920 A; 1920 B) on local races, comment being ventured only where our material throws some light on the problem of races, or where his work bears on the specific characters of the Pacific sardine.

Regan (1916) has relied upon gill raker counts, very largely, to separate as subspecies the Mediterranean and Atlantic forms of *Sardina pilchardus*, giving in specimens of comparable size (110–180 mm.) 63–82 for the Atlantic and 50–60 for the Mediterranean subspecies. His counts for Chilean, California, Japanese and South African specimens of *Sardina sagax* ranged from 70–105 gill rakers. The range of the counts made by us on Pacific forms is from 45 to 110 which includes all the extremes given by Regan. Unfortunately,

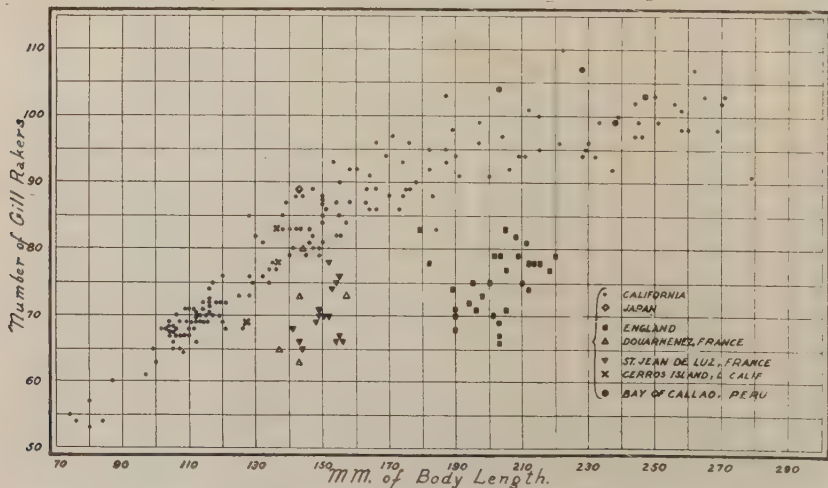


FIGURE 5. Number of gill rakers on lower limb of first arch in *Sardina sagax* and *S. pilchardus*. Plotted according to body length.

although he gave the range of sizes of his specimens, from his data it is difficult to judge of the exact variation of the counts with size, as he did not give the length and gill rakers for each individual, nor the number of fish upon which he based each range of counts. Therefore, there still remains some question as to the exact degree of variation between his forms, *Sardina pilchardus pilchardus* (Atlantic) and *Sardina pilchardus sardina* (Mediterranean).

It may be added that a 144 mm. specimen from Rikuoku, Japan, in the Stanford collection has a gill raker count of 89; four from the Bay of Callao, Peru, have body lengths of 246, 238, 229, and 203 mm. with counts of 103, 99, 107, and 104 respectively; three from Cerros Island, Lower California, of the body lengths of 127, 136 and 136 mm. have counts of 69, 78 and 83 respectively. As will be noted in comparison with the table and graph given, these fit in well enough with the counts for California sardines, although averaging somewhat high.

In view of such small variability existing in the far-flung Pacific

species, the presence of the difference Regan describes between the Atlantic and Mediterranean forms is highly interesting.

Fage, in the work previously cited, regards the varying head lengths as indicating races, a fact of interest because of the very obviously longer head of our form. We present certain of his data in table 4, to illustrate the degree of this variability. The greatest difference between any two of his localities is 1.7% of the total length, as compared to one of 2.1% between our English and California series.

It is entirely possible to calculate the probable theoretical difference which may be due to "chance" alone, and by such method decide the importance of this difference of 2.1%, but as has already been said, the material in our various series has been very differently preserved and this undoubtedly introduces a definite error dominating that due to "chance," where such small amounts are dealt with.

TABLE 4.—Length of head in per cents of total length.

	Total length 150-159 mm.		Total length, 160-169 mm.	
	Locality			
	Gulf of Lyon	Gulf of Gascony	Setubal	Gulf of Gascony
Head length in per cent of total.....	20.8	21.1	22.2	20.5
Probable error.....	±0.065	±0.042	±0.084	±0.057
Number of fish.....	75	79	27	28

The racial differences in vertebral counts of the European species made by Fage are great enough to cast doubt upon their value in distinguishing that form from the Pacific species. We present some of his data in table 5. Differences of many times the probable errors are shown. In one case—that of the series from the English channel—the mean is in excess of our counts, in several of the others the means are less. Consequently, as matters stand, the difference found by ourselves between the vertebral counts of our series of individuals from the Pacific and Atlantic ceases to be significant for distinction of species, although this difference is eight times the theoretically probable one were the series from the same sample.

TABLE 5.—Vertebral counts of European* sardines.

Number of vertebrae	Adriatic	Northern Mediterranean	Southern Mediterranean	Azores	Southern Atlantic	Gulf of Gascony	English Channel
49							
50	5	5	15		9	8	6
51	39	174	138	20	103	162	23
52	39	223	85	60	56	298	85
53	1	27		15	1	52	60
54					1	1	10
55							1
Number.....	84	429	238	95	170	521	185
Mean.....	51.42	51.63	51.29	51.95	51.31	51.76	52.25
Sigma.....	0.623	0.71	0.64	0.604	0.67	0.69	0.92
P. E.**.....	±0.045	±0.023	±0.028	±0.04	±0.034	±0.020	±0.045

*Taken from Fage, 1920 B, pp. 83 and 84. The hypural is included in our California counts, although we do not know whether it is in those made by Fage. In the second column there is evidently an error, as, for given frequencies, Sigma=56.

**The probable errors given in this and the following tables are those due to chance, supposing absolute accuracy in counting and the homogeneity of each sample—both conditions very improbably present. They are given simply to conform to present common usage.

Attention may be called to the fact that he gives counts of series from the Gulf of Gascony and the English Channel, the means being respectively $51.76 \pm .02$ and $52.25 \pm .045$, a difference of .49, which is ten times the expected difference were the two races the same, hence beyond the bounds of probability. But our series for the same localities give, respectively, $52.08 \pm .075$ and $52.13 \pm .07$, a difference of .05 as compared with an expected difference of .10, indicating that the counts are well within the limits of error, and apparently contradicting Fage's results.

We do not know whether Fage included the hypural in his count or not, but assuming that he did, the difference between his Gulf of Gascony counts and ours (St. Jean de Luz) is .32, compared with an expected difference of .08, therefore not likely to be accounted for by chance, but rather by error, or lack of homogeneity in the sardine population sampled.

The difference between the means of the two English series, that of Fage and that counted by us, is .12, with an expected difference of .08, which is well possible. But the standard deviation of Fage's series is given as 0.92, for which the probable error would be ± 0.02 ; that of our series is 0.71 ± 0.05 . The actual difference in standard deviation is therefore .21, compared to an expected difference, were the populations drawn upon the same, of .05. There is more than a suspicion of error in this dispersion of the counts, an impression which is decidedly strengthened upon comparing that of 0.92 with the dispersion of the counts for other localities given by Fage, which ranges from 0.60 to 0.71.

We are not, therefore, inclined to accept the evidence of the vertebral counts as indicative of races without further investigation. It is entirely possible that the count supposed to be characteristic for a given locality varies considerably from time to time, or as between one school of fish and another, or that differences in method of counting give rise to error. The calculated probable errors given are, in such a case, of no decisive significance.

However this may be, the supposed difference in vertebral count between the two species compared, European and American, can not be accepted, in view of the existence of Fage's results.

To conclude this discussion of morphological differences and "racial" differences, it can almost certainly be said that the variations within the species in vertebral count and in other characters do cloud to a certain extent the significance of the differences between the Atlantic and Pacific sardines. The exact extent of this clouding remains to be seen, as there is practically no evidence as to the races of the Pacific sardine and imperfect evidence as to those of the Atlantic. Moreover, it can not be expected that a perfectly clear definition of the variability within either species could be obtained even were the numbers utilized more extensive. To multiply such a number sufficiently to give a picture of every type of variability within a widespread and variable species is a serious undertaking, beyond the scope of the present investigation. Furthermore, the question as to the exact meaning of these "races," as related to "species" can not be settled

here, for it is, and has been for many years, a major problem of biology.

From this review of the species, it seems that the two species are quite sharply distinct in color, in gill raker structure and number, in scale characters, and very probably in body and head proportions.

It would appear that as regards life history, habits and edibility, the same comparison of racial and specific differences may possibly exist. The presumption is that there are well defined differences in some of these things, but in which regard they are well defined, in which they overlap, must be decided by investigation and trial. Reasoning from the characteristics of one species as to those of the other may have an element of probability, but of low degree.

We have, therefore, made free use of investigations upon the French sardine only wherever they seem to be applicable in a general way to the formation of the necessary program of investigation. Two important and admirable publications will be found to be most often referred to, namely that of Hoek, "Les Clupeides (le hareng excepté) et leurs migrations," in *Rapports et Procès-verbaux des Réunions*, Volume XVIII, *Rapports*, pages 1-60, Copenhagen, 1914; and that of Fage, "Engraulidae, Clupeidae," in *Report on the Danish Oceanographical Expeditions 1908-1910*, Volume II, A. 9, 1920. We have, however, refrained from applying to our Pacific species any particular facts of life history given by these.

No space need be spent upon the comparison of the few specimens of the remaining Pacific forms available to the writer. He has been unable to find clearly marked differences and as far as concerns other characters such as head length or vertebral number, it would appear futile to make comparisons without much more extensive series of individuals than are available. The presence of local races within our own waters or those of other countries bordering the Pacific may be important, but can not be touched upon here.

The sole paper upon the Japanese sardine is that by Kishinouye (1907), who gives very interesting notes but does not undertake an extensive analysis of the variations in the abundance and the catch.

In regard to other species which are or might be utilized as "sardines" in California, there is little to say. (The "sardine" of Norway is either herring or sprat; that of Maine is herring.) The Pacific herring, *Clupea pallasii*, is found in some abundance in Tomales Bay, San

Francisco Bay, and Monterey Bay, and has been reported at San Diego during the winter months. It comes in to spawn, and is never taken except during the few weeks required for this act. It is not canned as a sardine. There are also found in California three species of anchovies, *Engraulidae*, none of which are utilized, or seem suitable for use, as "sardines." A species of "Japanese herring," *Etrumeus*, is found near San Diego occasionally, but never in numbers. There seems, in fact, little possibility that the Californian canners have anything available which they can pack under the name save a true sardine, or pilchard, distinct from but closely related to the European sardine.

II. The Commercial Catch on the Pacific Coast.

The sardine on the Pacific coast is found abundantly from San Diego on the south to British Columbia on the north. That it extends, occasionally, at least, beyond these limits is not to be doubted; yet we have no test at hand for abundance save that of the amount utilized. The United States Bureau of Fisheries steamer *Albatross* took several specimens off Cerros Island, Lower California.

There are at present three main fishing ports in California; namely, Monterey, Los Angeles harbor, and San Diego. Although Santa Cruz⁶ has had, and Long Beach⁷ has at present canneries, they are of minor importance. The relative amount of sardines landed year by year in each of these three main ports is shown in the accompanying figure 6. Along the coast between Monterey and British Columbia no extensive use is made of the sardine.

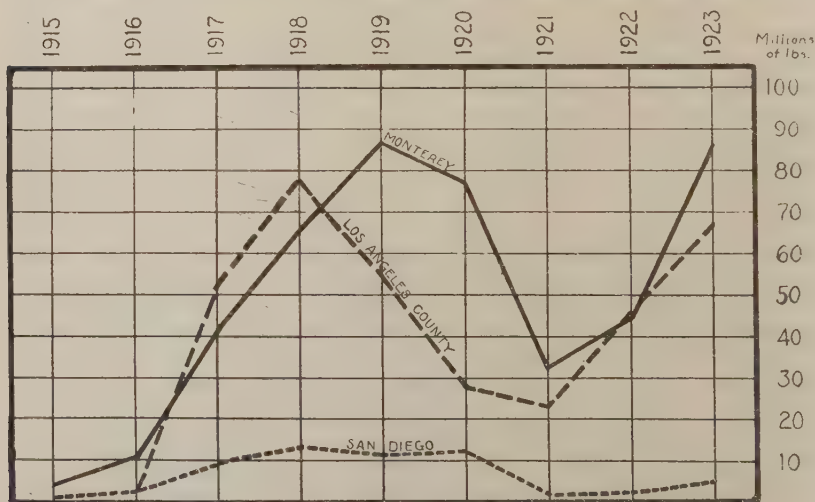


FIGURE 6. California sardine catch by statistical districts.

The value and quantity of the pack of pilchards in British Columbia has been as follows:⁸

Year	Value	Amount cwt.
1917	\$11,810	1,363
1918	413,853	72,723
1919	371,871	65,624
1920	540,265	88,050
1921	101,945	19,737
1922	106,055	20,342
1923	92,036	19,492

The decline shown may possibly have been due to market conditions. No exact information is available as to fishing areas in British

⁶ Included with Monterey, in this report.

⁷ Included with Los Angeles harbor.

⁸ Data from Canada, 1921 and 1923.

Columbia, but the fishery there is said to be carried on in protected channels by means of purse seine boats.

The fishing area at Monterey is located⁹ at the head of a very pronounced submarine trough, leading up from the edge of the continental shelf at 1500 fathoms. The 100 fathom line (well within which fishing is carried on) is approximately 10 miles from the shore line, and the general line of the continental shelf is slightly in excess of 35 miles off shore, hence there is a steep intervening fall unbroken by islands.

The fishing area at San Pedro is in sharp contrast. It is on the inner edge of a very wide part of the continental shelf, which is there about 165 miles from shore line to 1800 fathom line. "The surface of the shelf is disposed in broad irregular belts of alternate elevation and depression, the general trend of which is NNW. or parallel to the front line of the shelf" (Lawson, 1924). The water near the edge of the shelf is no deeper (300 fathoms) than it is near the shore. There are numerous deep basins in the three belts of deep water, and several islands are present. Between one of these, Santa Catalina and the shore, a distance of 21 miles, the sardine fishery is carried on, for the most part, within ten miles of the shore.

At San Diego the conditions are much the same as at San Pedro, save that the inner belt of depressions approaches more closely and there is no intervening island.

The ordinary minimum temperature of the sea water in southern California is in excess of the ordinary maximum at Monterey, and the maximum at the latter place is about two months later (August) than at San Diego. We know of no detailed contrast between the conditions prevailing in the two localities. Certain data are given by McEwen (1912 and 1916) and Hubbs (1925).

The economic factors in the making of the pack naturally include labor and shipping facilities. But the distances travelled by the boats and the degree of shelter from rough water are also factors in the cost of production. The result is, as it would be expected to be, a concentration of the canneries in particularly favorable spots. Just what part the distribution of the schools of fish have played in the matter is difficult to make out, although one is inclined to ignore it as a factor since it can hardly be an accident that the canning centers are all in ports with good shipping and labor advantages, and the only ones in a long extent of open coasts. That the location of the canneries is due to the natural abundance of fish in particular areas would seem extremely doubtful, it being far more probable that the fishing areas are determined by the location of the canneries.

But the massing of the schools at particular places is borne out by the summer fishery for young used as bait in the albacore fishery. The albacore fishermen travel for many miles to favored localities to capture the sardines of the first three- or four-year classes. See figure 7. It would, at first sight, seem rather absurd in the face of this to assume a general and widespread presence of sardines in oceanic waters, yet it

⁹ Hydrographic Office of the United States Navy, Bathymetric Chart, San Francisco to Point Descanso, compiled from data obtained with "Sonic Depth Finder," March 1923, Washington, D. C.

is entirely likely that these localities are chosen because it is only under the physical conditions prevailing there that the catches can be made.

However this may be, in narrowing observations to any one fishing port, the catch sampled becomes representative of the ocean within relatively few miles of the canneries, a well defined fishing zone. Mr. W. L. Scofield (mss.) states that 74 per cent of the catch in the season of 1921-1922 at Monterey was made within five miles of the canneries. There is no way of telling at present where the schools which enter these fishing zones come from. They may be migratory, and on the other hand, they may be highly localized. The record which is obtainable deals, then, with fish which are within, or which enter at various times, certain restricted areas, and the catch must, therefore, be to some degree a reflection of whatever migratory habits exist. That fact does not, however, indicate that migration is the sole, or even the most important factor involved in the appearance and disappearance of the

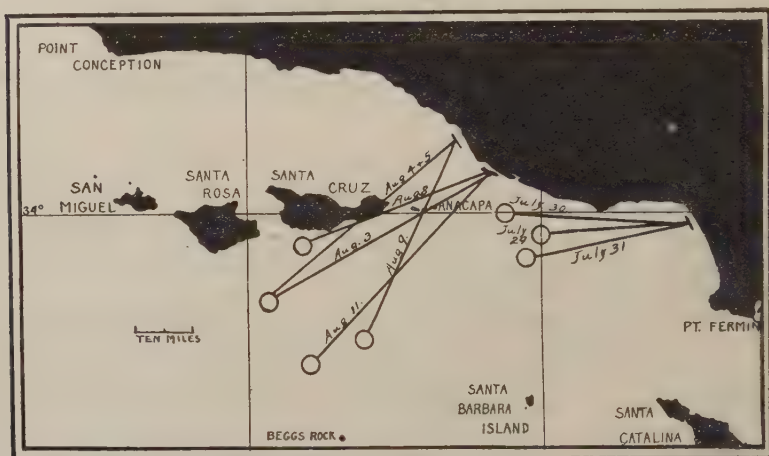


FIGURE 7. Fishing localities of the boat, Standard No. 1, July 29 to August 11, 1921. Showing by short lines where bait was caught, and by circles where the catch of albacore was made. (Data furnished by K. Yamashita.)

schools; it might, for instance, be superimposed on the effects produced by temperature.

However, the catch is the only existent record of the fish which enter or live in these zones. From this catch is made the pack, and it is natural to turn first of all to it for whatever information it may give.

In California localities the character of the pack has differed at times, but as a rule the smaller fish seem to characterize San Diego.

Sardines are packed in several different types of cans, containing a pound, half-pound, or quarter-pound, and our statistics record the number of cases of these packed. As in general the smaller the cans, the smaller the fish required to fill them, the record of the pack does to a certain extent indicate the size used. During the

six years from 1918 to 1923 inclusive, 32 per cent of the total pack at San Diego consisted of pound cans, while 74 per cent and 97 per cent

of the packs at Los Angeles harbor and at Monterey Bay, respectively, were of that size. This difference is shown more in detail for the summed period of six years mentioned below:

	San Diego	Los Angeles Harbor	Monterey
1 lb.-----	32.3%	73.6%	97.2%
$\frac{1}{2}$ lb.-----	13.3%	18.5%	2.4%
$\frac{1}{4}$ lb.-----	54.2%	7.9%	.4%
	99.8%	100.0%	100.0%

This uneven distribution of the various sizes of sardines parallels in a way the distribution of the sardine or pilchard in the region between the French-Spanish border and England. According to the various authors who have dealt with the subject, the majority of the sardines taken along the French coast are young and small, whereas those taken in England are large and old. (Fage, 1920A, 1920B; Hoek, 1914; Cunningham, 1896; Hjort, 1912; Smith, 1901.) Whether this is due to defective fishing methods, a natural difference in the habits of the fish or in distribution is hard to decide. There seems to have been little evidence adduced for or against either hypothesis, aside from the examination of the commercial take. On our own coast the demand of the canneries has much to do with the catch.

Least too much emphasis be placed on this seeming predominance in California of large fish to the northward, the changes in each locality from year to year in the percentage of the pack which were pound cans is shown in the following:

	1918	1919	1920	1921	1922	1923
San Diego-----	17%	39%	45%	13%	13%	40%
Los Angeles Harbor-----	43%	54%	92%	95%	98%	98%
Monterey Bay-----	96%	97%	97%	96%	100%	99%

As will be seen, the large fish were packed in San Diego during 1919 and 1920 in considerable percentage, while in Los Angeles harbor the percentage has steadily risen.

The percentage which quarter-pound fish form of the total packed in each locality is inversely correlated with the above, as the following illustrates. In these tables the half-pound category is neglected, and the contrast between localities made much sharper.

	1918	1919	1920	1921	1922	1923
San Diego-----	64%	46%	44%	86%	77%	54%
Los Angeles County-----	17%	15%	--	--	--	--
Monterey Bay-----	1%	1%	1%	--	--	--

The laboratory has had no trouble in obtaining from fishermen at San Pedro (Los Angeles harbor) young sardines, such as make quarter-oil packs, and it is difficult to convince oneself that there is a natural lack of them. It is, too, a fact that young sardines are used during the summer for albacore bait. But it is also true that the supply of quarter-oil sardines is everywhere unreliable, and for that reason the canneries must in the long run prefer to pack the larger sizes where such can be done most economically.

In so far as the fish taken to the northward of Monterey are concerned, there is little direct information available. Inquiries by letter

made of the packers in Puget Sound elicit the general statement that in 1923 the sardines (pilchards) were very large and very uniform in size. Mr. J. P. Babcock (1918) of the British Columbia Fisheries Department, says "The fish were large and fat. Many were sold fresh and several salmon canners packed them in one-pound and half-pound cans, and they met with ready sale." The Pacific Fisherman (August, 1924, p. 10) says "The fish, they (the packers) say, are full grown and of larger size than those caught in California waters." Also "Being 12-14 inches¹⁰ in length, they are too large to pack in one-pound ovals, California style."

In view of the fact that pilchards were only occasionally seen in British Columbia previous to 1916,¹¹ and the uniformity of their size, there would appear some ground for believing the abundance to be due to one or several unusually successful year classes, which will ultimately reach a very large size and disappear. This can not be told without some study of the age of those composing the run.

It is exceedingly regrettable that no attempt has been made to keep an exact record of these northern runs, as it would be interesting from the standpoint of their permanence, of the time of occurrence and of the composition, in comparison with southern runs.

Since large sizes predominate along such a great extent of coast line to the north, it is hardly conceivable that the lack of young there is due to a concentration at and south of San Diego. It is, on the other hand, possible that such variations in abundance occur between nearby localities and that such concentrations of young, unknown as yet, exist at various places along the coast. But the fact that the proportion of young packed during the early stages of the industry has shifted very considerably during the years, would seem to cast considerable doubt on the permanence if not the actual existence of such concentrations. Whereas, in the earlier years of 1918 and 1919 it seemed fairly certain to us that fish at Monterey were larger than at San Pedro, we can no longer say that such is the case. It therefore, remains very doubtful whether the seeming difference in distribution of adults and young as shown by the tables is correlated with any persistent variation in actual abundance of particular sizes in the ocean.

We are, therefore, faced in these peculiarities of distribution by an irregularity in the catch, which we can not definitely assign to widespread and uniform biological factors, which may, indeed, be an artifact, and which emphasizes the necessity for dealing with individual localities as a basis for understanding the catch. Our results must, therefore, be regarded as pertaining to these individual localities until their characteristics are sufficiently well known to justify comparisons.

It is also logically necessary, before attempting to assign the differences between localities to any one factor, such as migration or temperature, to review the possible factors and their effects.

The catch of sardines is seasonal, being rather definitely limited to a certain time of year in each locality. It is the general impression,

¹⁰ If by this total length including caudal is meant, this size corresponds to the largest taken in San Pedro in any quantity.

¹¹ Jordan and Starks (1895) state, however, that the sardine appears in Puget Sound in large numbers in the "warmer part of the season."

Seasonal Character of Catch.

however, that its extension, either by an early beginning or a late ending, is easily possible providing that it pays to make an extra effort for early fish or to use the late running, spent and thin schools. The correctness of this impression has been shown during the past year at San Pedro by one cannery which operated much later than the others, but in that case the catch of sardines fell off ultimately anyway. Again, it is the custom at Monterey to cease or begin operations just before or just after a full moon, when it is too light to detect the schools by their phosphorescence. It does not seem, indeed, advisable to lay too much emphasis upon the exact dates of the beginnings and endings of the seasons as biological phenomena.

In the accompanying figure (figure 8) the catch is given month by month from 1916 to 1923 inclusive, and the seasonal concentration is well shown for three localities, San Diego, San Pedro and Monterey. The three differ quite markedly. The bulk of the pack seems to occur during August, September and October at Monterey; during January, February and March at Los Angeles harbor. The season commences in June or July at Monterey and in December at Los Angeles harbor. At San Diego the season is distributed over the whole year, perhaps as a result of the small fish used there, yet the seasonal maximum corresponds to that at Los Angeles harbor.

The amount of sardines landed in California has varied quite widely from year to year. Figure 2 at the beginning of this paper, gives the totals for the calendar years. The rise of the pack was due to war conditions (Thompson, 1921, B, p. 195; Tariff Commission of United States, 1925), and its fall during 1920 and 1921 was due to a post-war collapse of the market, followed by a recovery. No one acquainted with the industry questions the fact that economic conditions caused the changes.

The division of the pack among the calendar years is, perhaps somewhat unnatural. For comparisons with other features of the various seasons, the seasons have been treated as units and the rise and fall of the pack shown in the upper section of figure 9, for Monterey and Los Angeles harbor (San Pedro). The slower response of the Monterey packers to the conditions is evident, although, perhaps, the early decline of the southern pack may have been due to the competition of Monterey. The effect of the economic upheaval of the war is very obvious, nevertheless.

An inspection of figure 8 showing the seasons, will bring to light the fact that the season at Los Angeles harbor began in December of every season except those of 1920-1921 and 1921-1922, two of the poorest, or "slump," years, when it began in January. At Monterey it began in June, and July was a fairly important month,

Beginning, End and Length of Seasons.

up to June of 1920, when the two months lost their importance. This they have not as yet recovered, although July of 1923 showed an improvement. The conclusion is a probable one, that the economic conditions determined the exact dates of the beginning of the season, although biological conditions may have determined the general season.

As regards the end, this came in June or July during 1917 and 1918 at Los Angeles harbor; but coincidental with the decline of the pack,

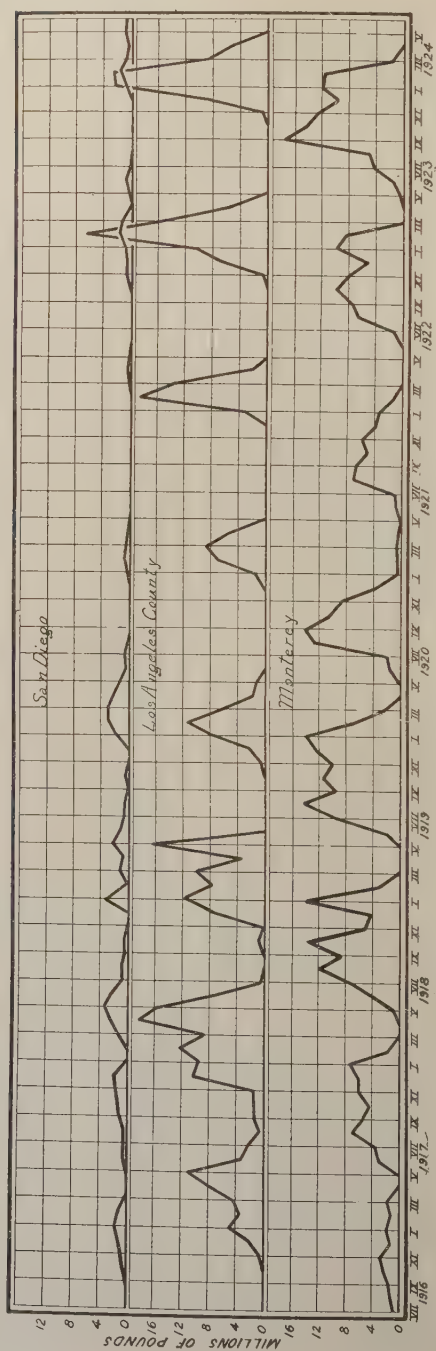


FIGURE 8. Total commercial catch of sardines at principal California ports, given monthly from 1916 to 1924. Data from California Fish and Game Commission.

the end came in May of 1919 and 1920; in April of 1921, 1922 and 1923. At Monterey the end during this period of years has come in February, with the single exception of the season of 1920-1921, when the pack in January was negligible. The connection of the end of the season with economic conditions seems to exist, but is not entirely clear.

The rather indefinite determination of the beginnings and ends, characterized as these are by rises and falls of varying degrees of abruptness, leads to a desire to secure some measure of the general length of the season which is more precise. For this purpose, the season's curves have been dealt with as our curves of size frequencies have been, by the calculation of the standard deviation. In doing this it is realized that the use is not strictly correct, but the measure does give an estimate of the "breadth" of the curves as representing the

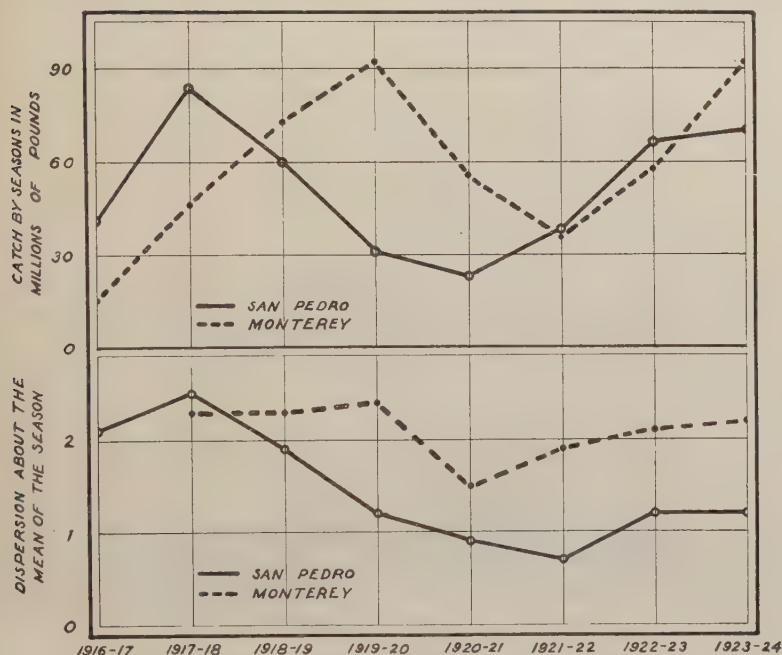


FIGURE 9. Comparison of sardines landed at Los Angeles harbor (San Pedro) and Monterey.

Above, total landed.

Below, length of season (dispersion about the mean).

length of the seasons. These standard deviation values are as follows, expressed as months:

Season of	Monterey	San Pedro
1916-17	--	2.1
1917-18	2.3	2.5
1918-19	2.3	1.9
1919-20	2.4	1.2
1920-21	1.5	.9
1921-22	1.9	.7
1922-23	2.1	1.2
1923-24	2.2	1.2

The diminished lengths of the two "slump" seasons are clear enough in the table, but for comparison with the amount of the seasons catch, there have been included in figure 9 two graphs representing this data for Monterey and San Pedro. The correlation between this measure of the length of the season and the total packed is particularly striking at San Pedro.

Just what the general shortening of the season at the latter place may mean is problematical.

In figure 8, the seasons of 1916 and 1917 may be easily compared with the last ones shown (1924). At San Pedro there is quite a marked shift in the season, as may be seen by observing the relative importance of January.

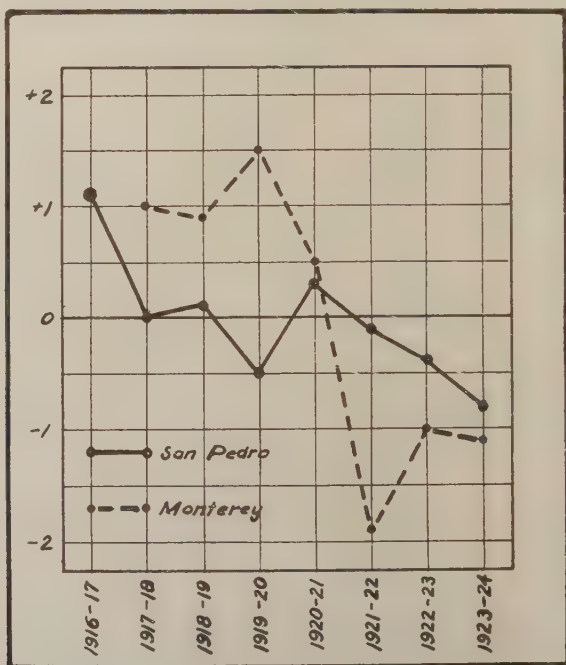


FIGURE 10. Shift of sardine seasons as shown by "mean" month of season.

For better examination of this, a value obtained during the above consideration of the length of the season was used. To obtain the standard deviation of each season's curve, what might be termed the mean, or average, months for the seasons were calculated. These, which we may look upon as the centers of the several seasons, are plotted in figure 10, as deviations from their means. The shift disclosed is fairly well defined, particularly at Monterey.

<i>Season of</i>	<i>Monterey</i>	<i>San Pedro</i>
1916-17-----	—	3.6
1917-18-----	10.0	2.5
1918-19-----	9.9	2.6
1919-20-----	10.5	2.0
1920-21-----	9.5	2.8
1921-22-----	7.1	2.4
1922-23-----	8.0	2.1
1923-24-----	7.9	1.7
Mean -----	9.0	2.5

There is no obvious cause for this, as far as the writer knows, although one is inclined to regard the change in the market for canned fish, fertilizer and oil as responsible at San Pedro. There the incoming of the lean, spent fish in April exists as an increasingly important reason for early closure. But there are so many possible economic explanations that much more careful analysis would be necessary than we are able to make at present.

When the two series of seasons for Monterey and Los Angeles harbor are compared closely it will be seen that if they were combined there would be a relatively small period of the year during which no sardines are landed. There was no such slack period before the war boom collapsed, but in 1920 the amount landed in May was inconsiderable and this has been true of every succeeding year shown. June shows a somewhat similar lack of importance. The same seasons may be seen in the catch at San Diego.

The seasons in the two localities, Monterey and Los Angeles harbor, overlap in the fall months. It will be readily seen that the season at Monterey tends to have two maxima, one in August or September and another in January, the latter corresponding to the maximum at Los Angeles harbor. The second maximum is lacking in the slack years of 1920 and 1921, but is particularly well defined in 1922 and 1923.

The nature of this relationship suggests that it is economic in origin, a slack period in orders preceding the opening of the Los Angeles season. Without an analysis of the packers' orders it would be rash to hazard a definite opinion.

In figure 11 are plotted the average catches for each of the several months for the period from July, 1916, to June, 1924, for the three localities. In these graphs are illustrated several of the matters already noted. The difference in seasons, the bimodality at Monterey, and the scatter of the San Diego catch are well shown.

From what has been said, it would seem plain enough that the fishing seasons are well defined, and that they are variable. They are variable to such an extent as to lead us to seriously question whether the causes of this variability are not potent enough to determine the permanent, or average, characteristics of the seasons.

Before we can assert these causes to be bio-

**Possible Causes of
the Characteristics
and of the Variability
of Seasons.**

logical in nature, it is incumbent upon us to ascertain to what extent economic and technologic causes may be responsible for the seasons and their changes. In the preceding pages more than a suspicion has been raised that these are very influential indeed. Although at this stage of the investigation it is hardly possible to make an accurate analysis, yet it is not out of place to indicate briefly some of the cruder possibilities in the case, and thus to explain to some extent the direction in which our investigations have gone.

In the history of the sardine fishery in California, there is plainly to be seen the influence of the lampara net in determining the season

and success of the sardine fishery, and of the economic conditions in the extent of the pack.

(See N. B. Scofield, 1924; also Thompson, 1921 B; and for a description of the methods of the sardine fishery, see Higgins and Holmes, 1921.)

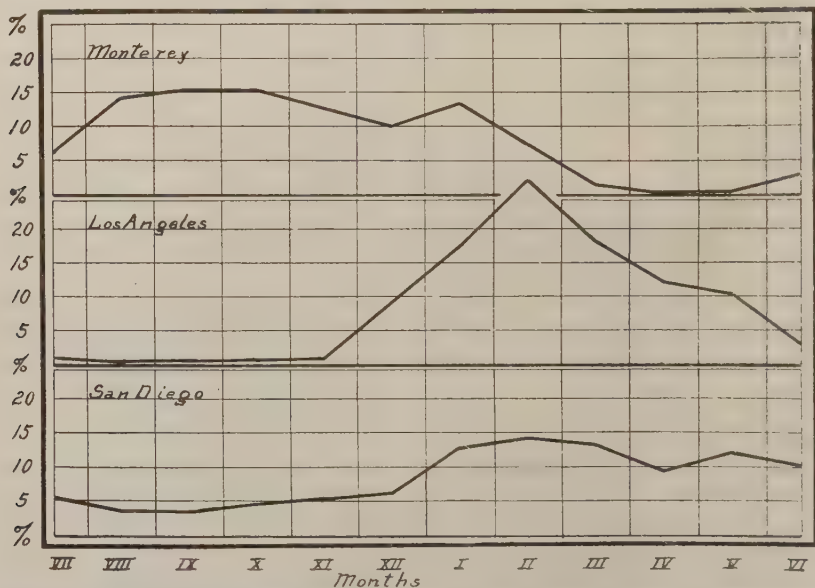


FIGURE 11. Distribution of sardine catch among the months, shown for each month as a percentage of the season's catch. For three important California ports, averaging July 1916, to June, 1924.

Within the areas fished, the sardines are captured by round haul, or lampara nets. These huge circle nets are not stationary but are cast by the fishermen upon the discovery of the schools. And because of this circumstance it becomes evident that the catch is made from those fish which come to the surface in large schools, and is probably not fairly representative of all the fish in the region. It is furthermore, entirely possible that the indications of the presence of schools are much plainer for certain sizes than for others, and that certain of these sizes are more easily taken. A slight difference in habit of spawning sardines, comparable to the torpid behavior of spawning Pacific herring, would result in their entire omission from the catch. Not having any manner of checking the catch against the actual abundance,

it seems to us wholly futile at present to speculate on the exact effect of the gear and of the skill of the fishermen upon the distribution of sizes within the catch and upon the seasons.

As Mr. Scofield says of the period before the lampara was introduced, "In those days the sardine season ended about the middle of December at Monterey. Now December and January are the big months and canning continues into March. In those days it was more difficult to make catches of sardines and the two canneries were frequently closed during the season on account of lack of fish. Now there is seldom a lack of sardines and this can not be explained on the theory that the fishermen have become more skilful through accumulated experience."

There must be considerable doubt, indeed, as to the representative nature of the catch, as different methods produce different results, giving different pictures of the catch, and different seasons.

This would seem to be obvious, indeed, from a simple inspection of the list making up the commercial catch of other species. There are so many varieties of which the captures are made in short seasons, or of certain sizes only, but which vanish completely from our ken at other times, and do not appear in any other place. We can not find in the fact that repeated trials at capture were in vain, any proof of the absence of the species. A classical instance is the disappearance during most of its life of the sockeye salmon, another the variable appearance of the albacore.

Again one has only to ponder over the many "rare" species in our waters, only occasionally taken, and to recollect that a certain measure of abundance in some locality must exist in each case in order that reproduction may be accomplished, to realize the limitation of fishing methods. An instance, one among many on our own coast is that of the lady-fish, *Albula vulpes*, of which we have as frequently taken the pelagic larvæ as in the case of other abundant species, but the adults of which are accounted an extreme rarity by fishermen and scientists alike.

The great and obvious seasonal failure of the gear used might be due, perhaps, to the behavior of the fish under differing conditions, rather than to any major biological change in abundance or otherwise. These conditions may be seemingly minor phenomena and may not, indeed, necessarily cause any great movement of fish or change of habits. Hunger in taking bait, the relative density and place of schooling, may possibly be affected by very slight changes in environment to give great effects on the catch. There would surely seem to be every likelihood that there would be as many and as complex conditions modifying behavior in water as on land, especially any behavior which has to do with feeding or schooling. And yet mankind is far from having analyzed some of the simpler occurrences in organisms directly under his eyes.

But entirely aside from such things there are cruder and more obvious reasons for doubting the exact meaning of our available data. For instance, there are serious economic reasons to doubt the repre-

Limitations of Capacity.

sentation of the abundance of any particular class during the different seasons. First, because at times the abundance is so great as to overwhelm the means of capture or preserving, and

hence, to destroy the sensitiveness of the record by necessitating a limit on the size of the catch. Such is true during a great part of our sardine season here, and has been noted during years of abundance in France, particularly when certain categories of fish are being taken. And secondly, because, although a given size may be present consistently in the same numbers, an increase in abundance of any other size will diminish automatically the proportionate representation of the first given size in the catch.

We have, therefore, been compelled to acknowledge at once that our outlook upon the natural abundance of the fish is through a medium, the commercial fishery, which surely distorts it, and which is affected in unknown ways by varying conditions. The nature of this medium, the fishery, must enter into all calculations, and the explanations of variations in abundance must first of all be sought in the method of the fishery and its peculiarities. However potent the biologic factors, they must almost necessarily be obscured and without clear definition among the welter of economic influences. It has seemed to us that this is one of the primary reasons for the failure of biology to contribute more than it has to our knowledge of what modifies the catch.

III. Fluctuations in the Catch of the European Sardine.

This view of the complexity of the data might well be discarded were there any evidence that the fluctuations in the French sardine fisheries have been readily assigned to a few simple causes. To see if such has occurred we may briefly review the facts presented by Fage and others. In that direction we must turn as to the nearest and most closely related field in which research has been done.

We have hesitated in attempting any analysis since we are so far removed from that fishery; and it may be that categories of facts inaccessible to us remain unrepresented in the literature. What is said regarding these fisheries is, of course, not a criticism of existing work, but rather a supplementary review from our own particular standpoint, since Fage and Hoek in their admirable treatises have given a better basis for analysis than we possess regarding our own fisheries, and have advanced most suggestive theories.

Fage (1920 B) states, regarding the various fisheries: The Mediterranean fisheries of France take individuals of all ages, but principally individuals completely adult, having spawned once or several times.

Variability and its Causes.

One of the most important consequences of this is the regularity in return of the fishery (page 65). Sardines of all ages are taken off the Portuguese coast and the fishery is very stable (page 74). South of the Gironde, at Bayonne and at Arcachon, the sardines commonly taken are in their second year and immature. North of the Gironde, at Sables d'Olonne, at Concarneau and at Douarnenez, the sardines are also in their second year. And it is in the fisheries of France to the north and south of the Gironde that the fluctuations are described as disastrous (page 77). The English pilehard is an adult, aged from four to eight years. The return of its fisheries are remarkable for their regularity (page 79). The greater the diversity of the ages of the sardines, the more regular the returns. Where, as in Portugal, sardines of from one to six years are taken, the unfavorable

result of one spawning is compensated for by that of others. But where, as in Brittany and Vendée, but one-year class is used, an unsuccessful spawning leads to a "sardine crisis" (pages 81 and 82).

It is clear that Fage tends to the opinion that it is the unequal birth rate which is responsible for the fluctuations in the French Atlantic fishery. That he is not certain that this is a complete explanation is obvious from his later treatment of the various effects of the environment. We may, for our purposes, see whether the evidence is clear and conclusive by carrying the analysis a step farther.

Fage's (1920 B) figures 24, 26, 27, 28, 29 and 30 furnish a view of the variability of the European sardine or pilchard. Hoek (1914) provides certain of the data upon which these figures are founded, and in addition gives statistics as to the yield of the west coast of England fisheries.

For an estimate of variability it is hardly fair to rely upon a record as short as that of Portugal, seven years, nor upon the catch in a locality which is unimportant, as Santander or the west coast of England. Were the latter used, the variations would certainly exceed anything found on the French coast, although the fishery is for adults.

We have, with the data at hand (from Hoek, 1914, and Fage, 1920 B) compared the records¹² for the various regions by means of logarithmic curves, which avoid the fallacy of comparing the absolute amount of the fluctuations in the catch when the average takes differ enormously.

These logarithmic curves are given in figure 12, and show the variations in their true perspective. The same general result could be attained by plotting the yearly catches in terms of per cent of the average catch.

It is very apparent that there are included in these, fluctuations of long period as well as of short. To illustrate this we have added to each of the graphs a trend, obtained by calculating the successive averages of the years' totals by groups of sevens, and plotting their logarithms.

It is evident that the catch on the west coast of England varies enormously, but, as we have noted, it is a small catch and lacks the stability of the very much greater one from the south coast of England. The former averages 478,800 kilograms, the latter 4,723,600 kilograms yearly.

It is also evident that the catches at Arcachon and Bayonne and at Brittany and Vendée vary more than the catches on the combined coasts of England, or on the Mediterranean coast, which substantiates Fage's opinion.

But the *trends* of the catches from the French Atlantic coast vary greatly, much more than those from the other regions. In fact a large share of the greater variability of the catch on that coast is fairly assignable to the diverging trends. The explanation of these trends must, therefore, be of considerable importance. The upward trend of the

fishery at Arcachon and Bayonne is said by Fage to be due to the use, after 1908, of motor fishing vessels. If so, the increase was accomplished

¹² Where the data are not given for any particular graph we have used measurements from the points given.

in the face of a literally enormous decline in the fisheries of the other French Atlantic localities, and the very important effect of a change in method of fishing clearly demonstrated. Whatever scarcity of fish existed was certainly of little consequence.

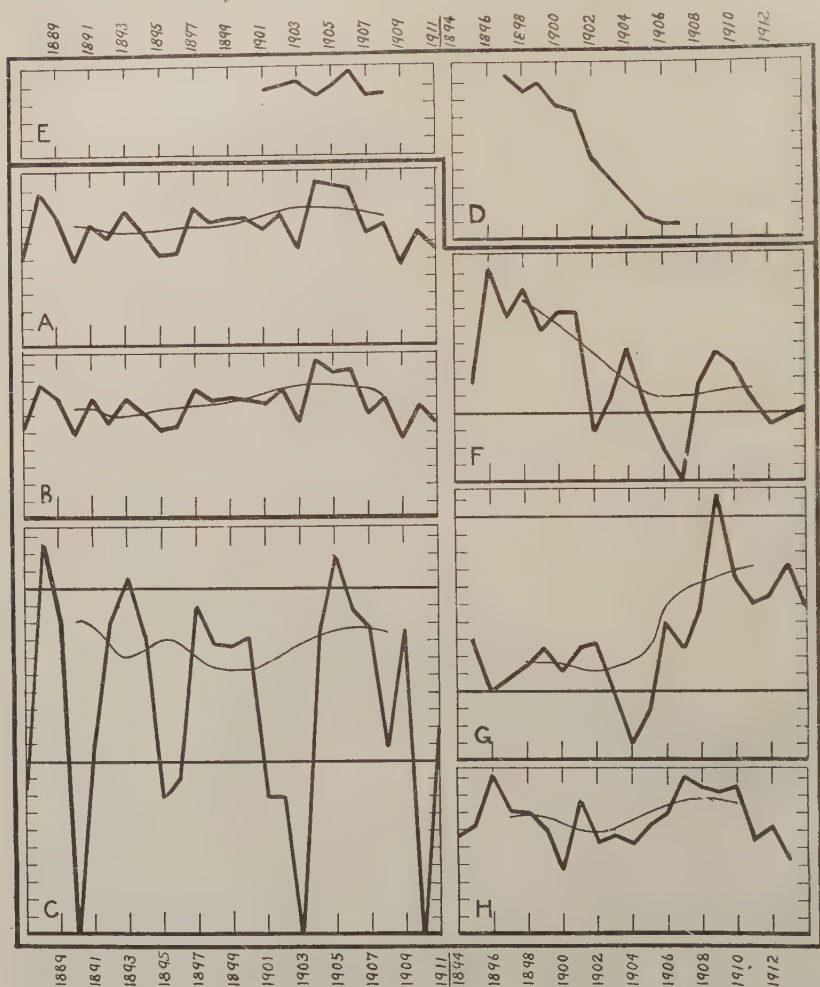


FIGURE 12. Fluctuations in the annual catches of sardines and pilchards in Europe. Logarithms of actual catches plotted on same scale in each case, one unit of the ordinate equalling the first figure of the mantissa, in order to represent fluctuations in their true proportions.

- A. Western and southern coasts of England, combined.
- B. South coast of England.
- C. West coast of England.
- D. Santander.
- E. Portugal.
- F. Brittany and Vendée.
- G. Arcachon and Bayonne.
- H. Mediterranean coast of France.

In the synchronous declines at Brittany and Vendée and at Santander, Fage (page 79) sees evidence of the homogeneity of the sardine

populations in the Gulf of Gascony and their response to the same laws. But it has been impossible for us to find in the works of Fage, Hoek or others, any positive evidence that these declines are due to biologic causes rather than to economic ones. As a matter of fact, it would seem logical to us to suppose these downward trends to be due to the failure of the world market for French sardines, referred to by so many authors (especially Hjort, 1912), affecting these localities alike.

The trends shown in figure 12, depend, even in the case of the French Atlantic fisheries, on many years' catches. Hence, were a lack of young existent for such a long period as to determine the trend, the effect should be obvious in the fishery for adults. We can not, therefore, find in the difference in trends of the English and French Atlantic fisheries a difference that can be assigned to the relative number of year classes found in the respective catches. Attention might furthermore be called to a certain similarity between the trends of the fisheries on the Mediterranean coast of France and those at Arcachon and Bayonne, fisheries that could not take their toll from the same body of fish.

It is necessary for us to conclude, therefore, that the causes of the decline in the French fisheries may possibly be economic in character—in part at least due to loss of markets, increasing cost of the fish roe bait used, etc.

If the trends are eliminated, it is interesting to note the relative variability of the fisheries for adults and those for young. To this end we present the plotted deviations (expressed as percentages of the means) from the trends for the more important localities in figure 13. The deviations do not give the impression of as great a difference in variability between the French fishery for young and the English and Mediterranean fisheries for adults as one would get from the original graphs.

However, the French Atlantic fisheries show variations of shorter period than the others.

Calculating a coefficient¹³ of variability for the deviations from the trend, using as a trend the moving averages of seven items, we find the following:

Brittany and Vendée	38.1
Mediterranean France	24.0
England, both coasts	28.4
England, south coast	24.6
England, west coast	92.2
Arcachon and Bayonne (including 1909)	83.1
Arcachon and Bayonne (excluding year 1909)	25.7

It does not seem entirely clear to us that the somewhat greater range of the deviations from the trends is necessarily due to biologic factors, since the uses made of the fish and the methods of the fisheries are

$$^{13}\text{Standard deviation} = \sqrt{\frac{\text{sum of deviations}^2}{n}} - \left(\frac{\text{sum of deviations}}{n} \right)^2$$

$$\text{Coefficient of variability} = \frac{\text{Standard deviation}}{\text{mean of annual catches}} \times 100$$

so widely different. But since our basis for reasoning is so limited, we very naturally can not make any positive statements.

More direct proof of the connection of the supply of fish with the size of the pack, and enlightening comment upon the conditions of the fisheries is given by Hjort (1912) but even in this case cause and effect are not shown to be connected. In the accompanying chart (figure 14), made from his figures, are shown the variations

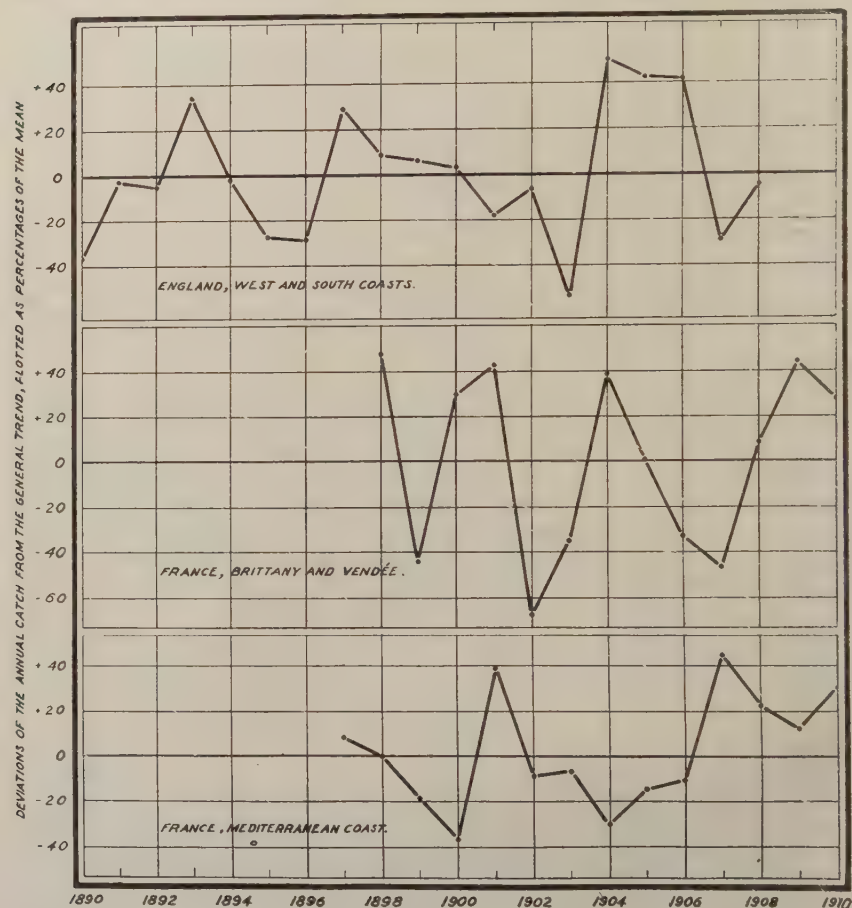


FIGURE 13. Fluctuations in the annual catch of sardines in three principal localities, expressed as deviations from the trend as shown by a moving average of seven years, and plotted as percentages of the means of the catches to show true proportions. Logarithms not used. Compare Figure 11, A, F, and H.

in the amount packed by a cannery. As will be seen, the period 1880-1886 was characterized by a very small pack, and other years were similarly affected. The selling price per case rose enormously during these periods, and this should, under proper analysis, indicate the condition of the supply. Gouault (1914, p. 8) also gives figures showing in a striking way the relationship of catch and price.

But according to the several authorities available to us, the small packs of the "sardine crises" were viewed in two ways. One view was that the scarcities were due to natural causes beyond the power of man to prevent. The other that they were due to the type of fishing gear used, and to economic conditions. (Hjort, 1912, p. 468; Fabre-Domergue, 1913; Hoek, 1914; Goualt, 1914.) On the economic side, two factors have been generally held to blame for the downward trend of the French fisheries. One of these was the increasing vigor of foreign competition; the other, the increasing cost of the fish roe used as bait. The part of the French government in restraining the free development of the fishing gear has been repeatedly and emphatically condemned as preventing the use of such gear as would meet the foreign competition and eliminate the use of roe (rogue).

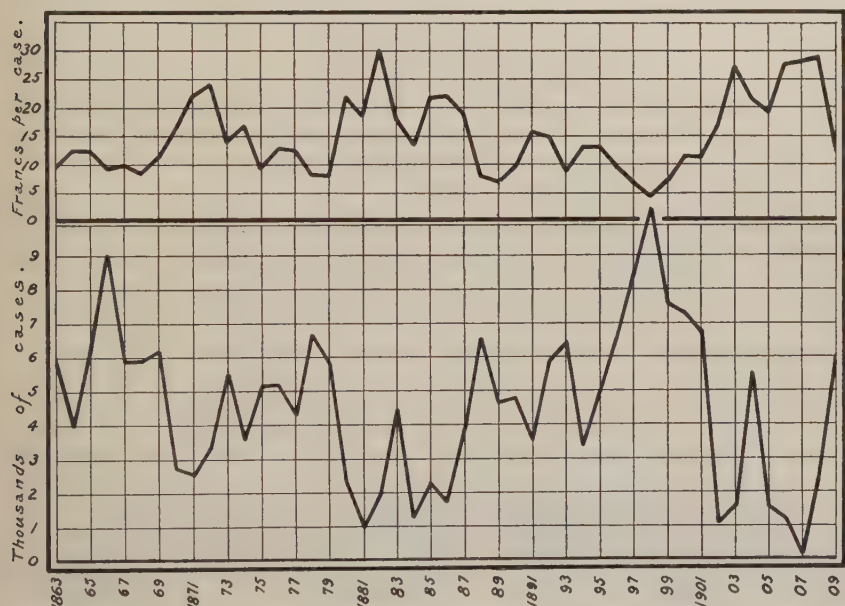


FIGURE 14. Amount and value of sardines packed by certain canneries in Brittany, France. Data from Hjort, 1912, p. 468.

Again, there is some question left in our minds after perusing the various reports, as to whether the fishermen did not effectively cause the prices to rise when the market was small, regardless of the true abundance of fish. The existence of a near monopoly, such as the French once had, would render such an attempt probable of success, and the passing of such a monopoly would cause great distress among the fishermen. The Fisheries News Service of the United States Department of Commerce, for August 15, 1924, records a dispute between the fishermen and cannerymen of Brittany, the fishermen objecting to the use of powered sloops by the cannerymen, and the latter asserting that "the fishermen have in the past deliberately restricted their sales in order to keep prices up." The existence of very great variability from year to year in the market demand, especially for a "luxury pack" such as the French quarter-oil sardines, is very obvious, on this

coast at least. What might seem a necessity, to the fishermen, of getting a high price during a poor market, would be plain.

It appears that there was a prolific source of variability in the methods of fishery. The small gill nets used with bait (cod roes) were incapable of the large catches made by seines, and the introduction of better gear such as purse seines was forbidden by law. (See Soc. Enseign. Bull. 1913, for the attempt made in that year to improve this condition.) Had this improved gear been intro-

duced, it could have alleviated the situation by lowering the cost of production, by catching several rather than one category of fish in abundance, and by being capable of making large catches during scarcity—at least in so far as we may judge by comparing our own Pacific coast fishery. Such gear would have been able, of course, to catch a great surplus during times of abundance, resulting in a necessity for limited boat catches. That is, as is well known, exactly what happens on the Californian coast, and the result is not unfavorable to the fishermen. It results in a loss for long periods of almost all traces of the effect of relative “abundance” of fish upon the amount of the catch. At the same time it should be remembered that the Californian fishery is for adults.

It seems to us, reading of the use of cod roe to entice the fish into the nets, that such a fishery must depend very largely upon the highly variable appetite and activity of the fish (Hoek, 1914, p. 10), whereas with the improved gear it would depend more upon their simple presence or absence at the surface.

In other words, granting for the moment a greater variability in the French Atlantic fishery, it might be due as much to the method of the fishery as to the actual abundance of fish. To quote Hoek, in his review of the finding of the committee whose report is in the “*Documents relatifs à la crise sardinière 1903–1907*.” The main cause of the insufficient yield during the poor season would, therefore, not be that there were no sardines, but rather that they were not caught in the nets, that they did not “work.” As soon as this condition of the fishery had once been established, the most important conclusion which could be drawn from the inquiry was that the parsimony which the high cost of the roe imposed on the fishermen was the fundamental cause of the poor season.

We are also impressed by the small cruising radius which resulted from the undecked, unpowered condition of the French boats in use in Brittany and Vendée. Looking at our own fisheries and the location of the catches, particularly in southern California, it would seem that such a small cruising radius would even here cause numerous periods of scarcity, since the “abundance” of sardines—or their accessibility—varies enormously within a few miles. Certainly the lack of power and the size of the boats must have been a prime factor in the variability of the French fisheries.

But we do not wish to be too positive in this conclusion. Our supposition that the improved gear renders the total take less sensitive to the changes in the accessibility of the fish is directly opposed to that of Fage (1920 B, p. 78), that better facilities at Arcachon and Bayonne led to a greater sensitiveness. Being in closer touch with the French fisheries, his opinion must be deferred to. However, either theory

attributes great importance to the effect of the gear, as distinct from the actual abundance.

Gourret (1894, p. 19) in commenting upon the decrease in quantity of sardines taken in 1890 as compared with 1889, in the Gulf of Marseille, says that the cause was not merely the bad weather in the gulf, but also the abundance of tuna, the capture of which was more profitable. Similar influences are from time to time recorded. A recent case is in the report of the American consul at Bordeaux, France, under date of October 27, 1924, that stormy weather was responsible for the diminished sardine pack in 1924. The existence of such influences leads one to wonder how many unrecorded influences of these sorts go toward making the "variability" in fishery returns—a variability the causes of which are later sought in biological factors, or which at least confuse the effect of the latter.

To further realize the complexity of the catch as met with, it may not be out of place to consider briefly some of the things which have been advanced as biological causes for changes in the stock of European sardines according to the review of the literature given by Hoek (1914) and according to Fage (1920).

Marine Conditions and the Catch of Young in France.

There is, indeed, but little actual data given in any of the French publications (for instance, Joubin, 1913) obtainable by us, to support the various hypotheses, but the latter are, nevertheless, given with a considerable air of assurance, which is the more disturbing in view of the poor records of the catch upon which any opinion must be based.

It seems evident to us that the physical surroundings may act in several distinct ways. First among them must be the effect due to death or survival at any of the stages of life, particularly at the younger. A good illustration of the possibilities would be the hypothesis advanced by Hjort (1914, p. 204) to explain the lack of abundance in certain year classes of the herring, that the proper food was lacking at the precise period that the larvae required it.

However, it is very evident from the literature that most authors have had in mind the direct effect of surrounding conditions upon the movements of the fish. For instance, A. Cligny (1914) refers to certain oceanographic phenomena with abnormal currents as possibly explaining the condition of the sardine fishery in 1905.

As regards food, Fage (1920 B) says that feeding is one of the main aims of young sardines in their annual visits to the coast of France and that a knowledge of the distribution of food is necessary to understand the movements of the fish. He proposes to study the qualitative, quantitative, annual or seasonal variations in abundance of the plankton and the influence of external factors on its dispersion and its relative abundance.

How indefinite this relationship still is, and how he relates it to other factors may be seen from the following translation from page 82 of his treatise (1920 B).

"The immature behave differently. Despite the insufficiency of our evidence and, notably, despite the absence of statistics permitting the establishment of the monthly schedule of their capture, it seems that, in

general, they arrive on the coast rather late in the spring, are numerous in the summer, remain until far in the autumn and disappear in winter. This is, at least, their habit in Brittany and Vendée, the only localities where they are exploited. It seems, then, that the thermic variations, the play of the currents, influence particularly strongly the plankton which they seek, and should play a basal rôle in the abundance or rarity of this category of individuals. Although we can not precisely measure this relationship—I have given, above, the reasons—we are not able to deny their existence. One finds at each instance, in the literature, examples of a nearly immediate reaction of the sardine to the abrupt changes of its environment. Such are persistent rains, sometimes a heavy storm, which closes the fishing season finally; sometimes a precocious spring coincides with their coming, equally precocious. There is no doubt that important variations occur in the course of the year, in temperature, salinity of the water, and in direction of currents, and one is not able to refuse to this ensemble a part in the explanation of the instability of the population, which constitute the immature sardines, coming to the coast in search of nourishment."

It would seem to be evident from this that Fage believes an immigration of the young sardines to occur, although he can not state from where, and that this is a search for food. We can not conceive that he had in mind an actual intelligent fore-knowledge on the part of the sardine as to the existence of food in French waters, and that when this was lacking the migration was not made, however much his statements tend to give this impression. He must, instead, have had in mind an adaptive migration stamped into the racial or specific habits of the sardine. In such a case, it would seem that the reasoning need not be confined to the single factor of food, but that it might be assumed the migration was adaptive in regard to food, temperature, enemies, and a host of other factors, constituting that ensemble of factors which one terms the whole environment.

It also seems to us that if such a migration is an inherited habit of the species, the theory might explain the normal action of the young, but that it is not very clear in its application to the variations from the normal. It might be supposed to call for the appearance of the young whether the food were there or not, and a further assumption would have to be made that the fish left the region upon failing to find food. It would, however, seem to us that no such intelligent or purposive reaction could be expected, nor could be assumed without proof. This proof, we believe, is lacking.

It would seem possible, of course, that the utility of planktonic studies might be very great in discovering the actual location of the schools at any given moment. Swithinbank and Bullen record, for instance, that the fish avoid the localities in which phytoplankton predominates. There remains to our mind, however, some doubt as to the utility of this indirect means of discovering the schools, since—at least on our coast—the schools are, whenever they are present at the surface, fully as easy to locate as the areas with phytoplankton would be, and we can not see that the coincidence of occurrence has been traced far enough to prove that avoidance or seeking of food influences the fish in any major way.

And it would seem that by far the simplest avenue of approach would be to study the migration of the fish directly—instead of indi-

rectly through a factor which is not known to be in even dominant control among that ensemble called environment.

As regards other influences, we have not been able to find any of them for which any actual proof of their operation has been adduced. Such things as storms which terminate a fishing season often occur in many other fisheries where the end is near or where the fishery has been unprofitable so that a resumption would not pay, and there are so many unusual occurrences each year to which the fishermen can assign any conceivable change in a fishery that we may be pardoned for being somewhat skeptical until an accurate record of the fishery and its changes forms a part of the proof.

Fage includes among the factors nearly all those mentioned by earlier authors, as may be seen by perusing Hoek's (1914) review. An exception is found, however, in a theory advanced by Bounhiol (1914). The latter, unlike his predecessors and colleagues, had the daily record of sardine landings in Algeria during a considerable number of years, and he ascribed the changes in catch to electric changes in the hydrosphere. We have been unable to find in the literature any of the detailed data of which he speaks.

Fage seems to lay as much stress upon the effect of these natural conditions upon the catch as he does upon the effect of variation in the success of spawning reviewed on page 31 of this introduction. It is evident from this, although he does not happen so to state, that he is far from denying the complexity and difficulty of the problems still to be faced in analyzing the commercial catch. To conclude, we are in hearty agreement with him, speaking from our limited experience, in assigning very considerable importance to the environment, both as it affects the number of offspring and as its complex conditions affect the individuals fished for, but we also desire to lay fully as much stress upon economic and technologic factors.

As regards the adult fish, the principal factors in their conduct are supposed by authors generally to be spawning, temperature and resultant migrations.

Fage, who gives, as far as we can see, the only positive evidence of the part played by spawning in producing a congregation which facilitates capture, states that off Portugal and Cornwall, the catch increases after the period of reproduction. His statements do not seem to be substantiated by the statistics which he gives for Portugal and the Azores, because the climax of the fishery (not well marked) comes so long after the spawning season as to justify its being regarded as preceding the next spawning.

It may be added that in our own fishery the maximum catch precedes the spawning, the coming in of spent fish virtually ending the season. In Cornwall, the maximum follows. One is inclined to agree with Bounhiol (1917, p. 477), who states that he can see no connection between catch and spawning.

The evidence of the effect of temperature upon spawning is more satisfactory. Fage, who presents it, seems to show clearly that spawning in the Mediterranean occurs during the winter months, but in the English Channel during the summer, the maximum temperature to the north in a cold climate equalling the minimum to the south, in a warm

Biological Conditions and the Adults: Spawning.

Temperature.

climate. The coincidence may well be significant. But lacking proof of the connection of spawning and catch, these facts have no immediate bearing upon our problem of analysis of the catch, although they may be ultimately important.

Along our own coast the same type of coincidence is found as to the catch and latitude, although not necessarily as to spawning. In figure 8 the catch month by month for San Diego, Los Angeles County and Monterey is shown. In southern waters the maximum is in February or March. But in British Columbia, far to the north, it is said to be between June and October. The existence of a bimodality in the Monterey catch is disturbing from this viewpoint.

It should, in passing, be said that, whereas, in European waters, the sardine is supposed to be seeking warmer or cooler water nearer its optimum requirements when it disappears from the surface, in our Californian waters the surface layers are always the warmer,¹⁴ but the fish nevertheless disappear at various seasons and times. (Compare Odin, 1896.) The theory is easy to apply and hard to prove.

The presence of local races, as demonstrated in the case of the European sardine (see page 14 *et seq.*) would preclude migrations of great extent. This is borne out by the general opinion of the scientists

Migration.

already cited, who have last investigated the sardine, that there are no great horizontal migrations. But the method of demonstrating these local races through physical measurements and counts is certainly not refined enough to throw much light on the relationship of localities very near one another, and migrations of sufficient extent to alter the catch in the small areas fished might easily occur.

It is, moreover, quite possible that such differences in physical characters are purely the immediate result of the particular environment in which a fish happens to grow up, and if this is true, the differences may exist even though there be an extensive drift of eggs and larvae from bank to bank. This drift might make fairly distantly removed populations dependent on each other, so far as numbers are concerned.

The matter of distribution and migration of the schools is not indeed a minor easily solved problem. There is no direct method of following the movement of the schools, and economic factors, as well as the behavior of the fish themselves, render difficult any accurate survey of relative abundance even between adjacent regions. There remains the possibility that the capture of the pelagic eggs of the species might give some clues to the distribution of the mature fish at the moment of spawning.

In view of the close relationship of our species with the European sardines, the findings in the case of the latter can not fail to be of interest. The only work of importance on this subject is that by Fage (1920 B, p. 36 and p. 45), reporting the results of the Danish Oceanographical Expedition. The captures were not sufficiently numerous to fix with accuracy the spawning places. The vessel was kept near the vicinity of the coast constantly while in the Mediterranean, and no information was available as to the distribution of the larvae in the high seas, although they were present as far from the coast as a

¹⁴ McEwen, 1916. "The temperature usually decreases continually as the depth increases and our observations have never revealed a 'reversal,' i.e., an increase in temperature with an increase in depth."

haul was made (70 miles off Naples). The hauls made in the Atlantic indicated that the spawning took place in coastal waters; no haul for eggs or larvae being successful at a greater distance than 70 miles from the coast.

It seems to us that no proof of migration is found in these facts, since there is no comparable survey of the distribution of the adults at other seasons. The question immediately arises as to whether the schools of sardines are in reality more or less localized at any given season than were the eggs and larvae at the time of their capture. It is certain that the fishery is carried on close to the shore. The sardine fishery, both in Europe and America, is a coastal fishery, all the captures being made within a score of miles from shore. To cite Hoek (1914, p. 62)—although we do not know at what distance from the coast the individual sardine is able, or accustomed, to go, we do know that the large schools are *met with* solely within a few miles of the coast. That does not mean that the schools of fish are nowhere else, for they might, indeed, be present without being visible at the surface to the fishermen, or it might well be that they are not sought wholeheartedly far from land. The tuna fishermen often speak of great schools far from land. The very fact that various sizes of fish disappear from view for long periods is sufficient proof of that possibility, whereas, if they could always be seen their migration could be traced. (As to the theory of migration and its bearing on the fluctuations in abundance, see Hoek, 1914, p. 6.)

One may, indeed, very justifiably challenge the representativeness of the sampling done by the commercial fishermen, limited as they are to relatively insufficient gear, hampered by economic factors, by their own failings, and by the habits of the fish. Lacking such accurate knowledge of the general distribution of adults during the nonbreeding season, it does not seem justifiable to make a loose assumption that any particular type of distribution of the grosser zones of maximum abundance during the breeding season means migration. The burden of proof certainly lies on him who would make such an assumption.

Without going any further into these phases of the subject, as the applicability of such theories to our Pacific species is questionable, regardless of their validity in French waters, it may suffice to say briefly that the problem of the great changes in abundance remains untouched by such reasoning. The major impression of value which we find ourselves able to draw from the European literature is that the conditions underlying and modifying the commercial catch are undoubtedly complex and difficult to analyze.

The result of this rather hasty consideration of the European fisheries for sardines convinces us that there are great fluctuations in them, and that the short period changes are nearly as pronounced in the fisheries for adults as they are in the fisheries for young. As to the causes for these, they are most certainly wrapped in obscurity. However probable the existence of biologic causes, the distinction of their effects from those of economic factors and of the methods of the fisheries, still seems to us to be incomplete and very difficult. The assignment of the effects to particular fluctuations in absolute abundance seems still further removed, and the use of gross fishery statistics to indicate changes in abundance is very plainly erroneous. The fact, nevertheless, remains that the theory advanced by Fage as to the great

significance of the varying success in spawning from year to year, is most logical and highly likely to be correct. But that any advance has been made in separating variations thus caused from economic and other changes remains to be proved.

IV. The Analysis of the Commercial Catch.

From our necessarily brief discussion preceding, it is evident that a multiplicity of factors may modify the commercial catch (as considered in its unanalyzed state) and render it far from a good sample of the species. We have, then, in the commercial catch as originating in a limited area, a sample which may or may not be, or may or may not contain within itself, a fair representation of the population of that area. Nor is there any justification for regarding the population of that area as representative of the whole species. It seems surprising to us that any scientific man can assume a simple relationship between the catch and the actual abundance.

It is, nevertheless, true that the commercial catch is by far the best available method of sampling. No private or public agency could afford to duplicate or parallel it, even were knowledge existent upon which a perfect system of sampling could be based. Indeed, the formulation of such a perfect system of sampling would require a perfect knowledge to start with. The scientist as a fisherman has no better tools to work with than has the commercial fisherman. He can simply apply better methods of recording and analyzing.

It has been assumed, therefore, as a basic principle of our investigations, that there must be direct proof before a fluctuation in catch can be assigned to any type of cause, such as migration.

But it has also been assumed that if natural abundance is of importance to the commercial catch, it will appear in modified form in that catch, although there may be so many changes in the latter as to confuse and obscure it.

It seems to us to follow directly from this point of view that the first step in any investigation is an accurate record of the changes which occur within the catch, the understanding of which is our primary object. It is not a matter of great moment whether that understanding carries us into an analysis of economic factors as well as biologic—we must go where the work calls. With the record available our analysis must begin, without any assumption as to the nature of the causes to be analyzed.

The question then arises, as to the manner of analysis of such a complex as the catch may be. If there are so many fluctuations, economic and biologic, superimposed upon each other, may not the task of analysis be hopeless?

In the first place, there is a distinction well worth making between investigations designed to explain the usual annual cycle of the fishery, and those which seek to discover and explain the variations from this.

**Usual Versus
Unusual Variations
From Year to Year.**

In the conduct of any industry there are more or less regular annual changes to which the industry adapts itself without great loss. The field crops are an illustration of this, and the fishing seasons are another. The fishing seasons,

just as the harvest times in the fields, are the result of natural seasonal changes, and may be expected to be properly taken into account. The lengthening of these seasons is, of course, desirable where the yield must be increased. Doubtless the product can be marketed and handled more economically when the annual cycle is eliminated. Yet that is not a fundamental necessity, as there may be a "rotation of crops"—sardine in winter, albacore in summer—thus using facilities all of the year, and the prolongation of the season would frequently cause too great a strain on the exploited species.

Furthermore, the elimination of the annual cycle is chiefly a matter of technique in fishing methods, the overcoming of natural obstacles to the taking of fish. Studies in natural history can, as a matter of fact, point out only in the most general way how this may be done. Although there is now very extensive knowledge of the life histories of many different species of fish, it is exceedingly doubtful whether this knowledge has proved in any way an assistance in eliminating the seasonal cycle in abundance. Perhaps this is because we owe the facts bearing upon distribution of fishes almost entirely to the explorations of the commercial fishermen, and because the latter's instruments for exploration are as perfect and far more often used than those of the scientist.

But the variations from this annual cycle, progressive failure of the catch or crop from over-fishing (exhaustion of soil, etc.) or its partial failure at irregular times, is everywhere reckoned most disastrous. All of mankind's economic life is built upon the annual cycle. The failure of one field crop, or of two in succession, means disaster because the financial reserve is not sufficient. So in the fisheries, the failure of several successive seasons, or even of one, is a real disaster, both to the fishermen concerned and to the capital invested. It is the more so in that it is not understood and is frequently regarded as a permanent change.

We find this fact of the relative importance of these failures, or departures from the regular cycle, clearly enough recognized by the French investigators of the sardine. As Hoek (1914, p. 3) says, and the truth of his statement is apparent, the natural history of the species has been studied earnestly in France, always with the hope that the investigations would throw light upon the irregularity in the fishery.

To us, however, it does not appear necessary that we analyze the details of the life history in order that we may analyze the departures of the commercial catch from the normal. What that normal yearly catch is may be determined directly, by the averaging of the take over a series of years, regardless of the complex factors which may enter into the formation of the "normal."

It seems to us, therefore, that the problem of studying the commercial catch is considerably simplified by first concentrating upon the departures from the normal. As we shall see, the departures from the normal will prove to be marked in nature and to betray something as to their causes by their characters. Once knowing what the fluctuations to be explained are, and knowing as much of their causes as they betray by their characteristics, it should be possible not only to make direct economic use of the characteristics of their entry and passage through the catch, but to approach the life history with definite problems to solve.

One would expect to find, paralleling a departure from normal of the catch, a departure from normal of the responsible condition.

Theoretically, therefore, there are to be expected two main types of fluctuations in yield. One of these is the fluctuation which is inherent in the fishery or the gear and constantly recurs season by season. It constitutes what we know as the usual, or average, run of fish, and is the net result of all factors in the situation. In our investigation we have assumed nothing as to how closely it corresponds

Type of Fluctuations Expected.

to the actual changes in abundance of fish within the fishing zones, or to any fact of the life history, since it is primarily a record of the sampling accomplished by the commercial fishermen. The definition, by accurate records, of this usual, or average, run of sardines is naturally of great interest to the industry, and to the scientist as well, despite the caution with which he must view it, because it is the basis of comparison upon which the unusual fluctuation is defined.

The other type of fluctuation is that which is an isolated occurrence or recurs only in successive transition phases from year to year and does not have a constancy of behavior which would allow it to contribute a definite feature to the character of the average run. It is, very naturally, as has been said above, these unforeseen variations which are most important and most disturbing. These include the changes due to over-fishing, those due to a varying birth rate, and those which are the immediate effect of changed fishing or environmental conditions.

Considering these departures from the normal it is natural to expect many kinds, ranging from a slow, steady shift in a given direction—in such a way as to change our definition of the normal or average, even when such is based on many years—to the change of brief duration soon counteracted by a change in an opposite direction.

Even a casual glance at the graphs for the French sardine catch, or those on our own coast, will demonstrate the fact that there are involved therein fluctuations of many amplitudes and of greatly varying durations in point of time. Granting that

Variety of Types of Fluctuation.

many of these are economic in origin, it remains true that there is good reason to expect variety and abundance of variations as a result of fluctuations in the supply itself, fluctuations that might be called biologic in contradistinction to those which are economic.

As an illustration we may discuss briefly from this standpoint the changes which might be brought about by the phenomena of the dominant year classes, due to unusually successful spawning years.

Theoretically, at least, there is no assurance that these dominant year classes due to single successful spawnings will represent always the same level of abundance. A dominant year class may well be a

Fluctuations of Long Period.

poor one and yet be dominant over its preceding neighbors simply because they are extremely poorly represented. In such cases the general average of abundance for a considerable period will suffer, although the phenomena of dominance are as clear as ever. There may well exist, then, a well-defined fluctuation in abundance over a long period, which age analysis will not show and which can be discovered solely by some measure of actual abundance, such as the

effort and gear required to take a given catch. If such a measure is observed over a short period of time only, the passage of a dominant year class must necessarily disturb its level profoundly. Hence, for the detection of these slow changes relatively long periods must be compared by means of measures of actual abundance, so that over- and under-abundant year classes may occur frequently enough to counteract each other and to yield reliable trends.

We confidently expect the effects of overfishing to be of the nature of relatively slow changes, and if we have been able to show in our Pacific coast sardine the phenomenon of dominant year classes, the detection of overfishing will become more difficult and time consuming, as has been said above. This will be true in regard to either the actual change in abundance or to that accompaniment of overfishing, the reduction in proportion of adults. The passage from young to adult of a dominant year class must act to confuse and delay any recognition of the more gradual decline in proportion of adults.

The extensive effect of such a dominating type of fluctuation must be felt throughout all work upon this phase of the sardine fishery. As was noted above where the various influences which might affect the

Effect of a things which may affect the level of the year's
Dominating Factor. catch. There seems to us no *a priori* reason why the variations in temperature conditions, salinity, food supply and many other things may not have their effects superimposed on each other and upon that of the dominant year classes, and why each of them may not cause as great a variety of changes in catch. Were the accuracy of the commercial sampling (the catch) beyond dispute, and the various factors accurately definable and of constant action, the case might be simpler of analysis, and approachable by mathematical methods. Yet, were, for instance, temperature the only factor modifying the catch it seems to us extremely unlikely that a simple linear relationship would exist or that it would persist as a constant throughout the physiological changes in the fish itself. As it is, it seems to us a necessary prerequisite to analysis that there be one overwhelming factor, so that its effect may be decisively shown.

We, therefore, have considered it well worth while to gather such data as will show whether there is such a dominant factor in the catch of California sardines. But we have also borne in mind the possibility

**Temporary Domi-
 nance of Different
 Factors.**

that in certain years one influence may be dominant, in another a different one; that there may be considerable hope of detecting instances where minimal requirements either for existence or for being caught are not met, or where some extraordinary change in catch is associated with some extraordinary change in conditions. Partly with this end in view we have sought to simplify our methods, to obtain as accurate a picture of the catch as possible, with the hope that some day the hydrographer or planktologist may be in a position to correlate his results with ours. At the same time we have felt strongly that experience has shown that in nature in general the small or graduated change is most frequent and most influential in the final summation, and also the most difficult of detection, so have not pitched our hopes too high.

In considering those changes in catch which occur within the fishing season as contrasted to those from year to year, we have found ourselves finally taking the same general viewpoint as in the case of the changes which occur from year to year. As in

Fluctuations

Within the Year.

the latter case, it would seem highly probable that the catch is affected by a melange of factors, some of which predominate in either a regular or an irregular fashion, and that this domination, if it exists, must result in confusing the associated factors.

To be specific, we might consider again the dominant year class as an instance. The various ages of fish are well known to have differing habits, and to run at differing times. Did one age predominate in the population, the whole tendency of the month by month, or day by day, history of the catch might be changed from what it would be were some other class dominant. The analysis is rendered thereby vastly more complicated and difficult. One might extend this reasoning to cases such as those in which temperature effects are overlaid by the variations due to visibility of the fish, etc., the whole aspect of the runs being changed by a lower average temperature or visibility.

It has seemed to us that a great deal of attention has been paid to the direct correlations which may exist between the behavior of the clupeoid fishes and outstanding features of their environment, with comparatively little result. Certainly the search for such correlations has not usually been accompanied by any thoroughly considered basis of statistical knowledge. We have hoped, in the following pages, to abandon this attitude, and to prepare our record, not merely for striking correlations of this type, but for some study of the less spectacular but more important minor variations.

We have hoped, indeed, that what we can not assign to specific causes we can ultimately treat by means of the laws of chance, expressing in mathematical terms the amplitude of changes caused, their average, their extent, and the variability existing in the appearance of whatever dominant types of change we are able to show—be their causes what they may.

At any rate the existence of the fluctuations must first be proved, as they diverge from the usual, or average, fishery. A start must be made from fundamental facts and the great body of existing suppositions and theories as to migrations, movements, etc., which have arisen from the indiscriminate consideration of peculiarities of the catch, must be boldly discarded.

It is firmly believed by the writer that in this program of accurate observation of the catch and its analysis into the various types of fluctuations lies the key to a real understanding of the catch. And in the catch lies nearly the whole of man's economic interest in the species, for thereby is made the latter's contribution to human food supply; and, conversely, through his take man reacts upon the submarine world. By means of this analysis those phenomena which are most important will come to attention and subsequent research may be intelligently and efficiently directed toward the proper connection of cause and effect.

Yet, and this brings to mind a prime consideration upon which our program is based, we must not forget that the *records* of the changes which occurred in Europe in the sardine fishery are largely

Necessity for Adequate Records.

lacking. It would seem almost self-evident that an understanding of a phenomenon can not be reached without knowing what the phenomenon actually is. A careful perusal of the literature has failed to bring to light any information as to what the great French sardine "crises" actually were. Hoek, Fage, Hjort and others present statistics of a sort which show the fact of great changes in the total yield, yet these do not go far enough to indicate whether they were due to economic or to biologic conditions. Their opinions alone must be depended upon.

We have referred on page 36 to the commission appointed to inquire into the cause of the French sardine "crises" of 1903-1907. The statements advanced that economic factors, rather than the biologic, were involved, would seem to have invited rebuttal by the biologists. There seems to have been no effective answer made.

There is, for instance, nothing given by Fage, in his work upon the *Clupeidae*, which will throw any light upon the rôle played by economic factors, seemingly for the simple reason that there was no positive information available. Nor does Hjort in any way prove the part played by economic conditions as distinct from biologic. Even in our own fisheries, after personal acquaintanceship of several years, one is entirely at a loss to separate the effects of the various biologic and economic influences without extensive special statistics very painfully gathered. The review of the French fisheries should emphatically indicate the need of such statistics.

In regard to this notable lack of statistical evidence, we can not do better than to cite the opinion of Fage (1920 B, p. 34), who undoubtedly speaks with authority, being a student of the subject and, as a resident of France, better fitted to express an opinion than ourselves. As Fage remarks, the available work on the sardine indicates that while the insufficiency of our knowledge of the sardine is due in large part to the lack of method and correlation in research, it is also due to the lack of available records as to the course of the fisheries and the fluctuations in their returns. Many of the questions which arise must be solved solely by statistics, which must be well made and comparable; and, as he says emphatically, it is astonishing to note the insufficiency of statistics for such a great fishery. Those of France have had their basis changed thrice, those of Portugal are based on sale prices, those of Spain and Italy are nonexistent, while the statistics in England, although good, are very recent. He enumerates the facts which should be included in those records, but are not—such as the monthly landings, the dates of appearance, the average sizes, etc.—and ends with a statement, the truth of which must be recognized: "La statistique biologique de la pêche, telle que Hjort (1914) la définit, devra s'imposer, tôt ou tard, à tous les pays soucieux d'exploiter rationnellement leurs mers." (Biological statistics of the fisheries, such as Hjort has defined, must be collected, sooner or later, by all countries desirous of exploiting their seas rationally.)

It seems to us to follow immediately from the fact of the great importance of the commercial catch of fish that accurate records be kept of its mere size, just as accurate records should be kept of the total number of inhabitants in a country. But also, to those with an intelligent interest in this commercial catch, the changes in its yield for

the effort involved become immediately of first concern. Records sufficiently detailed and exact to show these changes become a necessity, for there can be no real study of a phenomenon which is not defined—which may, indeed, be an artifact.

It may seem to many that this statement of our problems ignores to an undue extent the place of natural history investigations, using that term to mean the study of the habits, structure and the successive phases of the life of the fish. **Necessity for General Natural History Studies.** It is not intended, however, to forget the importance of such knowledge. On the contrary, we realize that a complete analysis of all the factors which underly the commercial catch would imply a thorough knowledge of life history.

It seems to us, however, a long and weary road before such a complete analysis is attained, if it ever is. To the best of our knowledge, there is no life history—even that of man himself—known so exactly and to such an extent that the multitudinous influences in it can be isolated and kept under continuous observation as possible causes of great changes in abundance, and it does not seem possible that any life history ever will be. Witness the incompleteness of our knowledge of the life and fluctuations in abundance of many birds and mammals which we are able to study intimately and carefully.

A review of the European work on the sardine and, indeed, on other species, shows that the greater part of the investigations have been carried on with purpose of understanding the normal phenomena of the life history. Using the work of Fage (1920 B) on the sardine, already repeatedly cited, as the best upon that species, it is possible to see that fact very clearly. There is a careful description of the young sardine and its mode of growth, a discussion of the time and place of spawning, the distribution of the larvae and of the typical appearance of the young and old in the fisheries. Limited as was Fage's material, it is of great interest as contributing to an understanding of life history. One understands, for instance, from a consideration of the plankton catches, that the young sardines are pelagic during their early life; and to a certain extent at least, the reason of their occurrence as young in coastal waters may thus be explainable. But, as has been said, such facts either explain in themselves only the customary phenomena, the regular cycle of events, or are in part merely statements of what actually happens, rather than reasons. They are for us of secondary importance, interested primarily as we are in the changes from the normal, and the effect upon the catch of what happens.

The place of a general knowledge of the life history is to us of a different character, that of guiding and directing. To illustrate, it might be necessary in order to study thoroughly the fluctuations in numbers within the successive year classes, not merely to carry on a census of the large fish, but to secure a determination of relative abundance of the younger stages from year to year. To do this accurately must require an exact and extensive knowledge of spawning areas and times, as well as of the dwelling places and time of occurrence of the later life phases. In the end this would mean the employment of a knowledge of the life history in order to extend to all stages that study which we find so difficult as applied to the adult—a census.

To us the discovery of dominant year classes among the adults alone is an important end in itself, and it is surely preliminary to any such census of the immature or very young, the usefulness of which would lie entirely in its explanation of the condition of the adults. But we find this study of the adults difficult, and feasible only in a limited way, so that at present we have not included any extension of it to the young in the details of our program. Hence, the apparent lack of studies of life history facts regarding the young. Whether we will ever find this extension of our work feasible, can not be foretold. If the difficulties in arriving at an absolute record of abundance of adults are also found in dealing with younger stages, the program of investigation would involve continuous and extensive surveys with plankton nets and young fish trawls, a program utterly impractical from a financial standpoint for us and, indeed, for many nations.

The need for a study of the general life history may also be illustrated readily by reference to a type of fluctuation other than those due to varying mortality in early stages. It is entirely possible that correlations of catch with changes in physical conditions may be pointed out to the investigator by particular facts of life history.

Bounhiol (1914) states that he has made such a direct correlation with the weather in Algiers, but we have been unable to find his detailed data. Allen (1909) correlates sunshine, plankton and mackerel through certain data as to feeding habits. But it does not seem necessary to review the literature of the subject, for the present condition and method of our fisheries are mute evidence of general failure. Attempts at such correlations have been made by naturalists for many years in many countries, without much success, or resultant aid in understanding the catch. To us it seems that the reason for such failures is plainly the lack of a statistical basis defining the phenomena to be explained. This basis we are attempting to provide.

There is, finally, a category of natural history facts which are very useful. This includes permanent traces left by the seasons on the hard structures of fish, and the morphological differences which arise from differing environments. These are natural history facts which form parts of the equipment of the biologist in attacking such problems as migration, rate of growth, the meaning of distinct size groups, etc. Remarks upon the use of age marks will be found on page 54.

We believe, in fact, that far from neglecting to utilize biological methods and facts in our statistical approach to the various problems, we have made their application more practical and feasible. We have collected biological statistics—using care in basing them securely, and in thus doing, *we seek to discover and define the phenomena before we find their explanations*, rather than the reverse.

As a matter of actual experience, the first obstacle we meet is our definition of what is loosely termed the "catch," used as an index to the abundance of fish. Considering the French sardine fishery, because

Necessity for Definitions of Catch.

nearest related to ours, there are evident great natural departures from the normal, and, indeed, our own Pacific coast fishery bears out this fact. Yet there is the most regrettable confusion between economic and biologic changes in supply, a confusion which renders use of ordinary statistics of "catch" impossible without refine-

ment. If one includes under the term economic the changes due to methods of fishing, it can be plainly seen that a complete separation is virtually impossible. It seems, in fact, that the best possible course is to come as *near* to a separation as possible, by the adoption of an arbitrary definition of what we term our "catch." This should be the most usable and practical one possible, and has been determined from a consideration of the material available, as discussed in the next section. It should include as far as possible only those changes which are due to natural conditions.

Our problems, then, may be stated as, first, of defining some concept which we can call the "catch" and which we can use as a basis for further analysis and also as an index to the varying abundance of the fish; second, of collecting adequate and accurate statistics bearing upon this "catch"; third, of defining the normal, or average, course of the "catch" from these records; and finally, of analyzing the resultant departures from the normal. The analysis of these departures will be directed to show the dominant type of fluctuation, whether it exists in some biologic category as a particular age or one sex, or whether it is in direct correlation with a phase of the environment. Finally, we must make some effort to show, in terms of the laws of chance, the types and degrees of variability which are left without analysis as to cause. Throughout, we must obtain as we go an adequate knowledge of natural history facts to guide and assist us.

V. Available Material for the Analysis of the Commercial Catch.

It remains to be seen what statistical and biological instruments we have available for the carrying out of such a program. We must determine in a practical way what it is possible to obtain and use. In the following pages we have defined and described the "catch" and the material collected for its study, remarking where necessary upon limitations and availability.

It has appealed to us as of very considerable importance to carefully define what we term the "catch." It is not synonymous with actual abundance, as we have remarked previously. Moreover, it consists not merely of quantity, but also of varying quality, for the great fluctuations in quantity are accompanied by changes in composition of the catch. And finally, the catch may mean anything from the total landed over a considerable area to that by a special type of gear in a particular place. Having, thus, considerable latitude, it is necessary to choose arbitrarily some particular definition which is most useful and most easily handled.

If we adopt the total catch of any one region for our purposes, it will represent a great many other things than the abundance of fish as it is commonly thought of. It will include the number of boats used, the habits of the fishermen, the market demand, the defects of the gear—in fact all the economic and biologic factors which have already been enumerated as affecting the available statistics.

There is, however, a more limited sense of the word, as used by the fishermen themselves in speaking of the abundance of fish. (All variations which are due to the behavior of the fish and which are inherent

in the method of fishing are regarded as variations in "abundance.") This is the catch of a unit of gear, or equipment, fished with normal skill and without hindrances for a given time. This catch, used as measure of abundance, is capable of very considerable refinement, by considering those catches made at certain hours only, or under certain conditions of relative darkness, or only when the schools are detected by certain selected methods. Any such modification would give distinct promise of rendering the returns more nearly those representing the fluctuations in relative abundance and in composition of the fish population although heightening the degree of selection.

But it is because it is the definition used by the fishermen in speaking of the abundance that the catch per boat per day is the most useful. The dealer or fisherman uses this as a basis in those calculations which they continually carry on during their business. It is what is normally obtainable by the application of a certain effort; it is what mankind can depend upon as a source of food; and it is the explanation of the fluctuations in this which is wanted.

It is also the easiest to secure, for it is the return from a certain unit of effort which determines the value, and it is clearly and naturally given in the bookkeeping carried on by the dealers.

The day's catch is landed as a unit, is paid for as a unit, and is what the dealers and fishermen are most vitally interested in. It is the only definite measure which runs through the whole fishery and which can be used in analyzing the commercial catch. It, therefore, serves as a good basis, not merely for the dealers and fishermen, but for our further analysis of the conditions affecting it and of its qualitative and quantitative composition. This further analysis involves the collection of supplementary data, and is a part of the special research involved.

For the study of the quantity of the catches, there is available in California a system of statistics of the boat catches which is accurate, reliable, and detailed in so far as it is possible to get such data and so far as it is not deliberately falsified. This system

Available Statistics. need not be described at great length, since its results are not used in the present papers except as it gives us the figures of total catch dealt with above (page 18). The State of California issues to the dealers, or cannerymen, a form in triplicate, upon which the receipt for the fisherman's catch is made out. This would be made out in the natural course of business, but the third copy is added for the state. Upon it are recorded the amount, the species, the date, the boat and the place of landing.

Invaluable as these data will be, and are at present in other fisheries, we have not yet used them save in part for the following reasons. The abundance of sardines is frequently so great as to completely overwhelm all means of capture or preservation save during periods of scarcity, and it is only such scarcities as reduce the catch per haul to a rather low limit that are, in the present state of exploitation, reflected in the take per boat or per day. No conceivable records of quantity could do otherwise. During these periods of abundance the canneries usually impose a limit on the size of the boat catch, which further prevents the true abundance showing. Statistics of the quantity of the boat catch are, then, so slow in responding to variations in natural conditions as to be misleading. As a consequence, indications as to the abundance of fish on any one day, or as to the relative abundance

at different parts of the season can not be relied upon without study of the qualifying conditions.

It may be pointed out, in this connection, that we have collected data upon the number of hauls necessary to make the boat catches. This is a truer and more sensitive index of the relative abundance as the fisherman sees it than the size of the boat load. Upon this phase we trust a later report may be issued, as well as upon the times and places the catches are made.

To the packer, or fisherman, and thereby to the human race as a whole, variations in abundance are of minor economic importance at present, since even during periods of lesser abundance, sufficient can be obtained. The changes in quality, in size and in maturity are now far more important. And in the ultimate analysis, these changes must be recorded and defined before any complete understanding of the catch can be attained.

Therefore, there remains for our immediate attention a qualitative examination of the catch; this consists of samples taken periodically, each sample representing a unit of catch as already defined. But since the quantity landed is dependent upon artificial limits imposed, the samples must be taken as a certain number per day. They do not, therefore, represent the abundance, but simply the time during which each particular quality of fish is taken.

It may seem, at first thought, that in undertaking such a qualitative examination, we are deliberately abandoning our aim of understanding the great fluctuations in quantity, including depletion from overfishing.

A System of Qualitative Sampling.

This is far from being true, however. It must be realized that our industry is in its first stages, that scarcities have not appeared, and that when our industry has come to take a greater proportionate toll, or when great scarcities do appear, the boat catches will begin to register the relative abundance and the time will be ripe for utilizing the data our statistical system is accumulating. This may now be true of the fishery at San Diego for small fish.

And in addition, we shall see that our qualitative studies give us a great deal of the information which will be necessary in understanding the fluctuations in abundance. There are two ways in which the abundance of fish may be affected, first by the variations in mortality rate at various stages of life preceding capture; and second by the direct effect of the environment upon the movements or habits of the fish. In the first of these the analysis for size or age must be of supreme utility, being the sole means of determining the relative proportion each age forms of the catch. In the second of these ways, a qualitative examination for age, size, sex, fatness, etc., may be equally as important as an examination of total amount taken, for it seems probable to us that changes in composition of the catch may go hand in hand with the fluctuations in quantity, particularly those due to overfishing.

When weighing the importance of these studies, from this standpoint, it must be remembered that the dominant type of fluctuation may obscure or render impossible of isolation minor types, and that the dominant type may well be the first named, that of varying early mortality, carrying in its train variations in quality equally as marked as those in quantity.

It is furthermore true as regards the economic importance of the investigations, that at present fluctuations in quality and size are of greatest interest. The periods during which certain classes of fish run are also of considerable concern. Upon all of these things a qualitative investigation is most promising of results.

Before embarking upon this system of sampling and utilizing it to show fluctuations in the stock of sardines, the fundamental limitation in its meaning as representing the catch should be carefully examined, as is done in detail in one of the attached papers.

Limitations in System of Sampling. This limitation is our inability to weight the samples according to the abundance of the particular groups that may be represented within them. When small fish are running exclusively they may be vastly more abundant than the large fish are when the latter predominate, but not be so represented in the samples, since the samples from a catch during an abundant run are no more numerous, nor larger, than samples from a poor run.

Were the "runs" of the several sizes sharply defined, this lack of ability to properly weight the data would lead to entire obliteration of any comparison between these groups as to abundance. On the other hand, were the several groups or categories correctly proportioned in each and every day's samples, it would follow that the grand total of those for the season would also correctly indicate the relative abundance.

However, as we shall see, the actual state of affairs is a compromise between those two conditions. The "runs" of particular sizes do have a certain independence, the more pronounced the greater the difference in size. But it is also true that the various sizes, particularly those nearest each other, are found together in the samples and to a considerable extent within their limits these do indicate the respective abundances. This will, of necessity, be treated at greater length in a separate section of this bulletin. It is a phase of sampling which we believe is generally ignored.

When instituting this system of sampling two major problems presented themselves. One of these was the amount of sampling necessary to portray the actual condition of the fishery.

Intensity of Sampling Necessary. The other was the categories of information it was desirable to include.

In regard to the first, it was felt very strongly that where the run varied markedly from time to time a hit or miss system of sampling could hardly help but misrepresent the facts. There was carried on, therefore, the most intense sampling possible with the funds and men available. The results were then examined by Mr. Sette to see how far the frequency of sampling could be reduced without altering the results. The reader is referred to Mr. Sette's accompanying paper for the conclusion.

In these samples, which were periodically collected, were listed as many of the characteristics of the individual as it was convenient to record. Among them were length, sex, state of maturity and—at times—such things as age, individual weights, degree of fatness, and bodily proportions.

So important is the analysis by age regarded at present that it is with the greatest regret that it is temporarily omitted. We—the director and the successive assistants—have vainly attempted to read

Age Analysis of Samples.

the age marks on the scales and otoliths. This does not mean that the attempt to utilize them will be abandoned. On the contrary, it is felt that the present work with the passage of dominant year classes through the catch has already led us to a partial knowledge of growth up to the ninth year or thereabouts. Having this knowledge we may be able to develop a method of accurately reading the scales according to the age their lengths should indicate. This attempt is already in progress.

For the purpose of giving a more adequate picture of the scale readings I have utilized a collection of 194 scales kindly made by Mr. George A. Rounsefell, of the laboratory staff, from the samples of sardines examined by him during the early winter of 1924.

In figure 15 is shown the curve of size frequencies for the 2500 individuals making up his samples for the period. The scales were

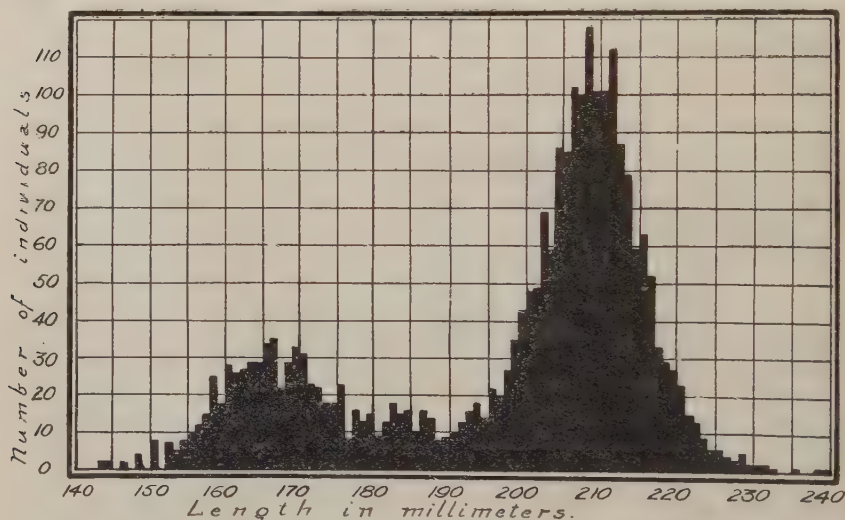


FIGURE 15. Frequency distribution of sizes of fish in samples taken during period covered by scale analysis, October to December of 1924. Made by George A. Rounsefell.

collected on the following dates: October 28th, 31st, November 4th, 7th, 18th, 21st, 25th, 28th, and December 2d, taking the first twenty out of one sample on each date.

In figure 16 are shown the size frequencies for the individuals from which scales were taken. It will be noted that the scale samples represent relatively accurately the distribution of sizes in the commercial catch, as this is shown by the sampling.

In the upper sections of figure 16 are shown these individuals separated according to the several ages represented. They seem to indicate that the larger size group is predominately of fish which have passed their fourth winter (IV group). These age readings are, however, for the most part questionable.

It was desired to use these fish under test conditions, and there were several precautions used in reading their scales. Since the usefulness of the scale method is greatest among the older groups, where size

frequency is no aid, an attempt was first made to eliminate all knowledge of the sizes the scales represented. These data were omitted from the labels, and the magnifications used were changed frequently in order that the size of the scale would have a minimum influence.

It was found that 54 per cent of the scales were marked as having questionable interpretations. Of the total, 194, 20 per cent were entirely illegible. There were 46 per cent of them which gave what seemed at the time acceptable readings.

These results were then set aside, and a second reading made, with the sizes before me. Of the 194 scales, 61 per cent were marked questionable, including 25 per cent entirely illegible. It will be noted that the questioned categories materially increased in size.

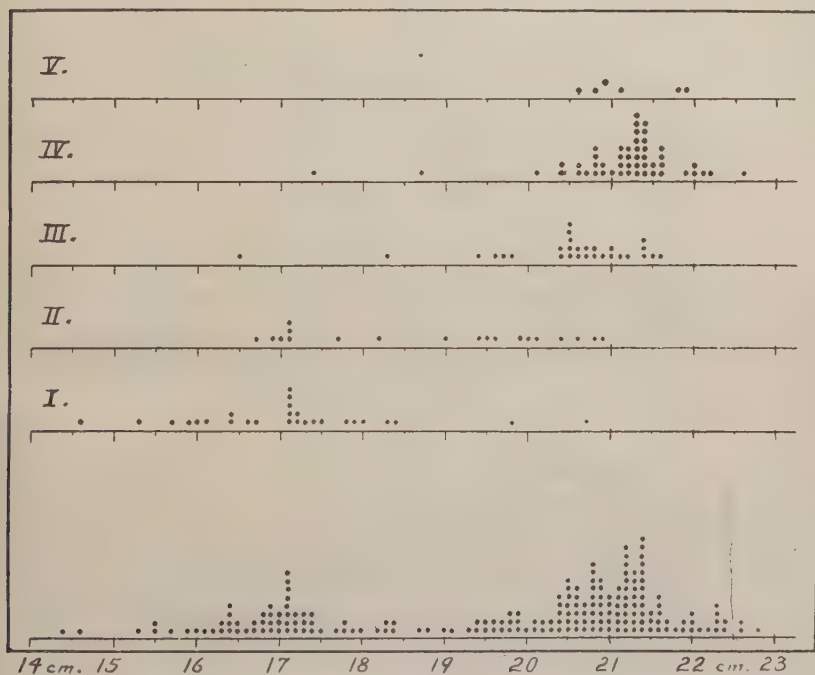


FIGURE 16. Size frequency distribution of fish whose scales were read and, above, distribution of these among the ages after the third attempt.

The most disquieting results were to be found in the changes in the interpretations made rather confidently at first. In the two series but 83 scales (43 per cent) showed the same readings, including in their numbers 34 questionable or illegible ones. In short, the comparison of the two series of readings indicated that but 25 per cent of the total were completely acceptable. The feeling of security in these acceptable readings was considerably diminished because of the 90 scale readings adopted without question in the first reading, 41 were changed or marked as questionable in the second.

The fact that scale readings were once accepted as conclusive, yet were later questioned and changed, is due to the attempt of the writer to convince himself that he could read the scales. Without such an attempt, he was inclined to discard the great majority of the scales as

hopeless. The impression of indefiniteness gained was quite different from the feeling of relative security left by the reading of herring scales, in the use of which the writer had previous experience. (Thompson, 1916.)

The effect of reference to the size of the fish when reading the scales was plainly shown by the number assigned to the I and II groups. In the first readings without reference there were 19 of these, in the second with reference, 52; both instances including questionable readings. There is no doubt, of course, as to the greater correctness of the

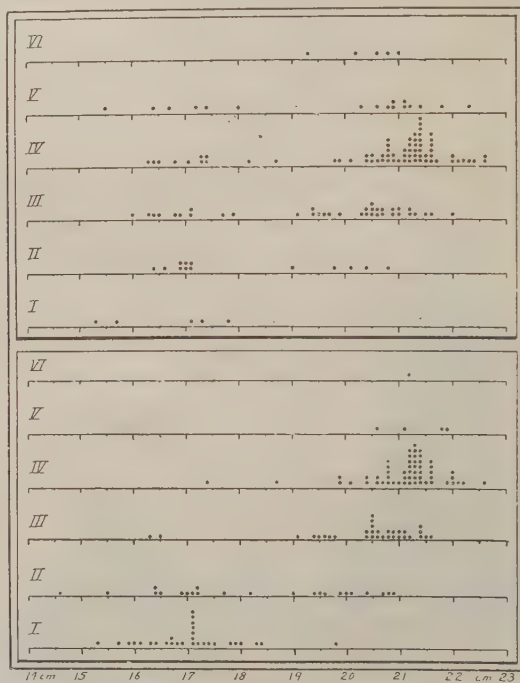


FIGURE 17. Size frequency distribution according to the several ages as read from scales. Readings from first attempt above, from second below.

second reading in this regard, since it was made with the lengths in mind, but were a similar difficulty met with among the older fish there would be no means of checking the interpretation, since the sizes do not differ markedly from age to age.

The assumption might be easily made, of course, that the errors would tend to fall on either side of the true value for each year class. That this assumption would be ill founded in the present case is obvious from the decided changes made in the proportion of the I group. If assigned to older groups these fish must necessarily cause an error in the average values.

From the marks used in age determination it is possible to calculate the length at each mark according to the method advanced by Lea and criticized by Lee and Molander. (Lea, 1910, 1913; Lee, 1912,

1920; Molander, 1917; Thompson, H., 1923.) This has been done, making no correction of any kind for the changing relationship of the scale to the body length nor for time of the first appearance of the scale. It is not intended that the results shall be regarded as accurate, as it is known beforehand that such very great errors exist as to overwhelm what errors in method are present.

In table 6 are presented the calculated lengths, at various ages, of

TABLE 6.—Apparent change in growth rate of sardine.

Age	Average length	No.	Calculated length at end of year.				
			I	II	III	IV	V
1.....	171.4	27	106				
2.....	188.4	19	98	162			
3.....	204.6	29	89	150	189		
4.....	211.3	50	86	146	180	203	
5.....	212.4	5	79	147	175	195	207

Age	Calculated increment during year				
	I	II	III	IV	V
1.....	106				
2.....	98	64			
3.....	89	61	39		
4.....	86	60	34	23	
5.....	79	68	28	20	12

fish which were taken from the two groups and whose scales were sufficiently distinct to be easily utilized.

In comparing these results with the size frequencies of the body lengths in the samples, it will be remembered that the smaller group, with a mode in the vicinity of 17 cm. was analyzed as composed predominately of fish with but one winter mark (I group). This modal size is, however, in excess of the average size calculated as existent when the second winter mark was formed. The fish designated as over one year old (I group) were, therefore, not merely exceedingly large for their age, but too large for the two-year group, as calculated from the scales of fish four (or five) years old. It will also be noted that the average length of the second-year fish is almost the same as the calculated length at the third winter. (Compare time of sampling.)

My determination of the age of these fish may, therefore, have been again in error, the changes made in the second reading being also erroneously made.

However, these mistakes contribute to what has been called the "phenomenon of apparent change in growth rate," wherein the first year's growth seems much greater in young fish. (Lee, *loc. cit.*, 1912.) I have tabulated the readings in the customary form to show this change.

With this simple presentation of results the use of scale readings is concluded for the time being.

VI. Collection of Data.

With the purpose of collecting as extensive data as it lay within our power to collect, daily samples were taken (when possible) during the winter season of 1919-1920 by Messrs. Elmer Higgins and Harlan

Methods of

Collecting Data.

B. Holmes at East San Pedro, and during the winter season of 1919-1920 by Mr. O. E. Sette at Monterey. At San Pedro the collection of daily samples was continued through the winter of 1920-1921, with the help of Mr. Holmes, but subsequently the samples were taken twice a week by Mr. Higgins. The collection of daily samples was continued at Monterey until the fall of 1923, when they were also taken biweekly there, by Mr. W. L. Scofield. The latter was assisted by Mr. O. E. Sette during the winter of 1922-1923.

In taking the samples, regard was had primarily to the number of men available, and the best application of their efforts. Thus in Los Angeles County the canneries were in 1919 somewhat scattered, it



FIGURE 18. Sardine scale patterns to illustrate confusion in peripheral annuli on otherwise clearly marked scale. (Camera lucida drawing.) Made by Ruth Miller.

being at times necessary to go to Wilmington or even to Long Beach. It was found that taking samples from five individual boats consumed enough time so that the remainder of the working day was largely utilized in taking a record of the observations upon these five samples, of twenty fish each. The case at Monterey was somewhat different, it being necessary to take the samples during the night and to examine them the next day, but the same arrangement was found to be expedient. In both cases the effort was to secure the most extensive data possible.

Some doubt was felt as to whether it would be better to take a greater number of samples with fewer individuals in each, or whether one sample of a great many fish would suffice. It was soon found that the single sample had a relatively narrow range, and that the variation between the means of the samples was very great. A good picture of either the length frequency distribution of the means of the samples for the day in question, or of the frequency distribution of the individuals in each sample, could not be obtained without neglect of the

other. The arrangement of five samples of twenty individuals each was an arbitrary compromise, based partly upon the feasibility of obtaining this number with some regularity, and it is freely admitted that the error in the final picture of the seasonal frequencies of sizes might be reduced by a careful study of circumstances. This phase of our sampling is, therefore, incompletely dealt with, only the general fact being held in mind, that the sample is to some extent the unit of variability rather than the individual fish.

This incompleteness of sampling would be far more serious were it not one of many errors. For instance, the variability is perhaps very great between seasonal "runs," etc., which variability in a broad way very largely invalidates the sampling as strictly representative of the fish in the ocean, and renders it of value *mainly from a comparative standpoint*.

The reason for a reduction in the numbers of days during which samples were taken was lack of men to carry on both field sampling and analysis of data. The reduction from daily to biweekly samplings was made as the result of Mr. Sette's study, with a view towards preserving the total size frequency for the season for comparison with subsequent years, and with the hope that even the months (as parts of the seasons) of successive years might be comparable.

The analysis of fluctuations within the season will necessarily depend largely upon the data collected daily, and for that reason the daily collection at Monterey was continued after the biweekly was adopted at San Pedro. The accompanying papers do not deal with this analysis of intraseasonal fluctuations to any extent, although enough has been done to show that it is highly important and interesting. The resultant data are very extensive indeed.

Each individual sample was taken from a separate boat catch. A bucketful was dipped up from the deck of the vessel, or from the fish conveyor as the fish were carried into the cannery; care being taken that the selection was random. Modifications in the taking of the sample were carefully noted and are mentioned wherever pertinent. Regarding the sample, the locality of capture, the landing place, the hour of capture, and the boat name were recorded. In addition, the number of hauls required were noted at Monterey during part of the time. Taken to the laboratory, the samples were observed without delay for:

1. Body length
2. Total length
3. Sex
4. Approximate state of maturity

as well as other data when desired.

Body length was defined as that between the projecting tip of the mandible and the last of the silvery area on the caudal peduncle after the scales were scraped away. Occasionally irregular projections of this silvery area were present, but these were disregarded. To check this, the total length was taken, including the caudal fin, when the rays of this were brought into a line parallel with the body axis. The fish were always measured when perfectly fresh, as soon as possible after landing. At times *rigor mortis* was present, distorting the body. In such cases the body was flexed back and forth until it would lie flat,

but such procedure was not often necessary. The lengths having been secured, the body cavity was slashed open, sex and maturity noted, and the fish discarded unless special additional data were desired.

Measurements for any one season were always made by the same man, to avoid personal error. Errors due to the deformation of the caudal fin, and those due to misreading of the length scale were guarded against by comparison of the two length measurements, body and total. The ratio of the total length to the body length depended, error aside, upon the length of the caudal rays. The latter varied in normal chance fashion around the mean caudal length characteristic of each size of fish, and the frequency distribution once obtained with its standard deviation and mean, the range admissible was readily calculated as six times the standard deviation. A table of maxima and minima, calculated for every half centimeter of body length served the various workers as a means of checking body and total length measurements, enabling markedly abnormal records to be remeasured or discarded.

The data were tabulated, size frequency tables prepared for each day on special forms and further analysis undertaken as described in the separate reports. A careful check of every copy and every operation was made as standard laboratory practice, using calculating machines and standard forms.

The measuring machines used were patterned to some extent after those in use in Europe for measuring plaice, etc. The one in use at Monterey was illustrated in the Report of the British Columbia Commissioner of Fisheries, 1916, Victoria, B. C., pp. 39-87. It was used by the writer in measuring herring. The other, used at San Pedro, was essentially similar, although improved in several ways by the writer and Mr. Higgins. The principle used was that of placing a fish parallel to a millimeter rule and projecting vertically on this rule the points desired. In the case of the tip of the mandible, a "nose-block" accurately placed, sufficed; and in the case of the other points a cross wire, hung on a projecting arm from a block sliding on a straight edge back of the rule, was used. To insure the correct placing of the cross wire, the projecting arm was jointed to allow vertical movement, and the wire itself was in practice aligned with its image as reflected in a mirror below the rule. Measurements were made to the smallest possible unit, the millimeter, in order to avoid any personal error in throwing the ascertained length to a larger unit. Further details will be given by the several assistants reporting.

There have been obtained extensive data not dealt with in these preliminary reports. There may be listed among these the following:

1. Various measurements for detection of locality differences in proportions of body and numerical characters, including preparation of skeletons.
2. State of maturity of samples obtained.
3. Eggs and larvae, not yet separated from the plankton hauls taken by the commission boat *Albacore*.
4. Determination of relative fatness of San Pedro sardines.
5. Samples of scales for age determination.
6. Catch locality records at Monterey and San Pedro.
7. Sizes below those of commercial catch for determination of early ages.

VII. Conclusion.

The logical development of the work begun by these papers is the more accurate definition of those fluctuations, which occur systematically enough to be of importance and to preserve their individuality from year to year. The extension of the study of dominant age groups back into the earliest sizes obtainable, the ascertainment of the cycle these groups pass through in the commercial catch, and the foretelling of the character of this catch through our studies of the young—these things are objectives—which will demand considerable effort and which will be worth while.

They will be worth while, not merely for their commercial value, but as steps in the detection of overfishing. From what we have shown in these papers it is obvious that the discovery of overfishing must take many more years than were thought at first.

They will also be worth while from the biological standpoint, in that they will give a clearer idea of the state of numerical variability exhibited by a group of organisms. Perhaps they will contribute something toward an analysis of the conditions and of the inherited characters, such as egg production, which lead to the overwhelming abundance or the near disappearance of species in the struggle for existence. It is something, at least, to know how and to what extent the numbers of a species vary, and where the causal mortality arises.

It is sincerely to be hoped that the observation of the catch will proceed, and that as the years pass the analysis will be carried further and further until it can meet and connect with the results of students of marine conditions. Even now, as soon as the age of our sardines is accurately known, our dominant year classes may be referred back to their year of origin, and it should be possible to select those years in which unfavorable conditions prevailed.

But from our studies it is also plain that the detection of overfishing must depend on a careful record of relative abundance as shown by the boat catches. This record is not obtainable now. But the beginnings of this statistical record are in the hands of the State of California—only criminal carelessness could allow its abandonment or the failure to improve and develop it.

An understanding of the work done and the program undertaken would not be complete without reference to the fact that it has developed in its entirety from the initial consideration of related problems,

Acknowledgements. especially that on the albacore, which the writer has undertaken at the same time. His work thereon has, moreover, made him very critical of the scientific character of much of the information usually compiled in fishery research, and the presence of several related fishery problems in our minds has aided greatly in defining to us what we now deem the proper aims of fishery research such as this. The program here presented has, indeed, been in continuous process of change and development, is frankly imperfect, and it is hoped will always remain plastic.

The writer has been throughout responsible for the formulation of the program and has overseen its execution. Initially concerned with the details of the work, he has sought consistently to leave these and as much freedom of action as possible to his assistants, and to increase

that freedom as rapidly as their training allowed. In accordance with this policy, conferences have been held, with all persons concerned present, as frequently as possible and every step has been discussed by everyone. A somewhat rigidly critical spirit prevailed in these discussions. Even details of technique have thus come to be common property, and no manner of dividing the credit for the work can be readily devised. It seems just, however, this cooperation being understood, that the various assistants should be held responsible for the phases of the problem with which they have been particularly concerned, and they have therefore reported separately.

The writer wishes to acknowledge the deep obligations he is under to each of his co-workers. They have contributed greatly to that part of the work for which he is responsible, in that they have been enthusiastic, widely read, and have quickly adopted a spirit of friendly but acute criticism. Their acquiescence has been sought in every step. That the report has not progressed farther is in no sense their fault, the collection of field data of this sort being in itself a monumental task.

Acknowledgement is also due to Mr. N. B. Scofield, in charge of the Commercial Fisheries Department of the commission. He has patiently and enthusiastically supported the program, which owed its origin to his own farsighted desire to care for the fisheries. And he has taken part in our conferences whenever possible and has contributed his personal views frequently, so that he should in a sense be co-author in each of these papers.

To Dr. F. W. Weymouth of Stanford University, who has also taken part frequently in our conferences, our heartiest thanks are due for much friendly help and criticism. We also owe much to Dr. C. H. Gilbert, retiring head of the Stanford Zoology Department, both for accommodations of workers and advice. We wish to express our thanks to Dr. W. K. Fisher, director of the Hopkins Marine Station at Pacific Grove, for accommodations there and numerous courtesies which enabled us to pursue our investigations at Monterey.

Miss Frances Clark and Miss Ruth Miller as librarians have aided the writer and the various assistants in many ways. The bibliography has been checked and listed by Miss Miller. Certain of the plates were kindly drawn by William Herrington, George Rounsefell and Miss Miller. To Mrs. W. F. Thompson the writer owes much help.

TABLE 1.—Measurements in percentage of body length and in counts of sardines.

San Pedro, California.

Number	Sex	Body length, mm.	Body depth, per cent	Maxillary length, per cent	Head length, per cent	Distance snout to insertion of—			Counts of		
						Dorsal, per cent	Ventral, per cent	Anal, per cent	Gill rakers	Dorsal rays	Scales l. l.
1.	M	215	20.5	12.1	24.7	44.7	53.0	78.2		19	57
2.	F	230	20.4	11.3	23.9	45.2	54.4	80.5		18	58
3.	F	275	21.8	10.5	23.3	44.4	52.4	80.0		18	60
4.	M	221	19.9	11.3	24.0	44.4	52.5	79.2		19	56
5.	M	192	21.4	11.5	24.0	43.7	51.6	78.7		19	57
6.	F	262	20.2	10.7	22.5	44.3	51.6	79.8		19	58
7.	M	209	19.6	11.5	24.4	44.5	54.1	79.0		18	58
8.	F	255	21.2	11.0	23.9	45.1	52.9	81.2		19	57
9.	M	167	20.4	11.4	25.8	42.5	52.1	76.6		18	58
10.	M	176	19.9	11.4	25.0	43.7	51.7	77.8		18	56
11.	F	242	21.5	10.7	24.0	45.1	51.7	78.5		18	59
12.	M	171	19.3	11.1	23.4	43.9	50.9	76.6		18	59
13.	?	155	21.3	11.6	24.5	40.0	52.9	80.0			58
14.	M	249	20.5	11.2	23.3	43.8	51.8	79.1		18	55
Mean		215.6	20.56	11.24	24.05	43.95	52.40	78.94		18.4	57.6

St. Jean de Luz, France.

1.	F	155	21.9	10.3	21.3	42.0	49.7	73.6	67	18	
2.	F	141	22.0	9.9	22.7	42.6		73.1	68	18	54
3.	F	155	20.0	10.3	23.2	43.2	49.1	74.8	75	18	54
4.	M	151	21.9	9.9	21.8	43.7	47.7	75.5	70	17	54
5.	M	149	22.8	10.7	22.8	42.9	49.0	75.2	69	18	53
6.	F	152	20.4	9.9	23.0	44.7	50.7	75.7	78	18	55
7.	M	144	20.8	10.4	22.9	43.8	50.0	74.4	65	18	53
8.	?	154	22.1	10.4	23.4	42.2	49.3	74.7	66	18	56
9.	M	156	19.2	9.6	21.2	41.8	48.0	74.4	66	18	54
10.	M	153	20.9	10.5	22.2	42.5	49.0	75.2	74	18	56
11.	M	143	22.4	9.8	23.8	42.7	49.0	74.0	66	18	53
12.	F	155	21.3	10.3	23.2	44.5	49.0	73.6	76	18	53
13.	M	152	21.0	10.5	23.0	44.1	47.4	74.4	70	18	51
14.	F	149	20.8	9.4	22.8	43.0	47.6	73.2	70	17	54
15.	M	149	21.5	10.1	22.1	41.6	48.3	73.2	71	19	53
Mean		150.5	21.27	10.13	22.63	43.02	48.84	74.33	70.1	17.9	53.8

England.

1.	M	205	23.9	9.5	22.9	44.8	50.7	78.5	77	18	55
2.	F	220	20.5	9.5	21.4	43.2	47.3	74.4	79	17	54
3.	F	210	21.4	9.6	21.9	43.8	48.1	76.2	75	17	54
4.	M	182	23.1	9.5	22.5	42.3	47.3	74.1	78	17	53
5.	M	190	22.6	9.7	22.1	42.6	47.4	74.7	70	18	53
6.	F	213	22.1	9.3	19.2	44.1	50.0	76.1	78	18	53
7.	F	203	23.2	9.8	22.7	42.9	48.8	74.4	67	17	54
8.	F	189	22.2	9.9	23.3	45.0	47.6	75.1	74	17	53
9.	F	200	21.5	9.7	21.5	42.0	48.0	75.0	75	18	52
10.	F	211	22.3	9.5	21.3	45.0	48.9	74.4	81	18	52
11.	F	202	21.8	9.9	20.8	43.1	48.5	74.8	79	18	52
12.	F	205	21.9	9.5	22.0	42.0	46.8		71	18	51
13.	M	201	21.6	9.5	21.9	43.3	48.3	75.6	70	17	52
14.	F	218	20.6	9.2	21.5	43.6	48.2	73.4	77	18	55
15.	F	203	21.7	10.3	21.2	43.3	48.3	74.4	79	19	53
16.	F	195	20.5	9.2	21.0	42.6	48.2	75.4	75	18	53
17.	M	203	21.2	10.1	22.2	41.9	47.8	74.0	69	17	53
18.	F	205	22.0	10.0	22.0	44.9	48.8	75.6	83	18	53
19.	F	212	23.1	9.9	21.7	43.4	47.2	76.9	78	18	53
20.	M	196	23.0	10.2	23.5	42.9	48.5	74.0	71	18	52
21.	F	203	22.7	9.7	20.7	41.9	47.8	73.9	66	19	54
22.	M	198	23.2	10.4	22.7	43.4	49.0	72.2	73	17	52
23.	F	194	21.7	9.8	21.7	41.8	44.9	74.2	72	19	53
24.	M	212	21.2	10.4	22.6	44.8	46.7	74.1	74	19	55
25.	F	209	21.1	10.1	21.5	43.5	47.9	76.1	79	18	52
26.	M	215	19.1	9.5	22.3	43.2	47.5	74.4	78	18	53
27.	M	190	22.1	10.0	22.1	42.6	47.9	76.3	68	19	54
28.	F	208	22.1	9.6	23.6	44.2	48.6	75.0	82	19	55
29.	M	190	23.1	10.0	22.6	43.7	47.4	75.3	71	18	52
30.	F	179	22.3	9.8	21.8	42.5	46.9	72.6	83	18	52
Mean		202.0	21.96	9.77	21.94	43.28	47.98	72.37	75.1	17.9	53.1

TABLE 3.—Gill Raker Counts of Sardines.

San Pedro, California

Length	Gill rakers	Length	Gill rakers	Length	Gill rakers	Length	Gill rakers	Length	Gill rakers
64	45	106	70	114	72	176	96	230	96
74	55	107	65	115	69	178	90	232	94
76	54	107	67	115	70	182	92	233	99
80	53	107	69	116	71	182	95	237	92
80	57	108	65	116	71	187	95	239	100
84	54	108	67	116	72	187	103	244	97
87	60	109	67	116	72	190	94	244	102
97	61	109	69	116	74	191	91	245	99
99	65	109	71	117	70	197	96	246	97
100	63	110	68	117	75	197	99	250	103
102	68	110	71	118	72	200	91	251	99
103	68	111	68	119	70	204	97	256	102
104	68	111	69	119	72	206	92	258	98
104	68	111	71	120	69	209	94	258	101
104	69	112	66	120	76	211	94	260	98
105	65	112	69	121	68	212	101	262	107
105	66	112	70	121	72	215	95	265	103
105	67	112	70	125	73	215	100	269	98
105	67	113	69	126	68	221	96	270	102
105	68	113	70	163	87	222	110	271	103
105	68	114	69	171	97	228	94	279	91
105	68	114	71	174	93	229	95		

San Diego, California

128	73	136	77	144	88	150	84	155	85
128	76	138	83	145	79	150	85	155	90
128	85	138	85	146	81	150	87	157	84
129	75	139	87	146	83	150	88	158	87
130	82	140	79	147	80	150	88	158	92
132	76	140	83	147	82	151	86	160	92
132	81	141	80	147	89	153	93		
134	75	142	83	149	79	154	82		
134	77	142	88	149	80	154	87		
135	78	143	83	150	81	155	82		

Monterey, California

163	89	166	89	173	86	183	88		
164	86	166	96	174	88	184	83		
164	91	169	94	175	89	187	93		
166	86	170	88	176	89	189	98		

Ceros Island, Lower California

127	69	136	83	137	78				
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Bay of Callao, Peru

203	104	228	107	238	99	247	103		
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Japan

143	89								
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Douarnenez, France

137	65	143	63	143	73	144	80	157	73
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England

179	83	194	72	202	79	205	77	212	74
182	78	195	75	203	66	205	83	212	78
189	74	196	71	203	67	208	82	214	78
190	68	198	73	203	69	209	79	216	78
190	70	200	75	203	79	210	75	218	77
190	71	201	70	205	71	211	81	220	79

St Jean De Luz, France

141	68	148	69	151	70	153	74	155	67
143	66	149	70	152	70	154	66	155	76
144	65	149	71	152	78	154	75	156	66

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SAMPLING THE CALIFORNIA SARDINE: A STUDY OF THE ADEQUACY OF VARIOUS SYSTEMS AT MONTEREY

By

OSCAR ELTON SETTE.

This paper is No. II of a series published by the Fish and Game Commission of California in Fish Bulletin No. 11, and is Contribution No. 53 of the California State Fisheries Laboratory. It was submitted for publication virtually in the present form in April, 1924.

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SAMPLING THE CALIFORNIA SARDINE: A STUDY OF THE ADEQUACY OF VARIOUS SYSTEMS AT MONTEREY.

By OSCAR ELTON SETTE.

The welfare of the fishery for the California sardine (*Sardina caerulea*) is the object of an intensive investigation begun in the fall of 1919. In this investigation it is proposed to study those aspects of the sardine population which are fundamental in the problems of conservation. These were succinctly enumerated by several questions in a previous publication,¹ and it may be advisable to reiterate those of greatest significance. They are the following: Will depletion occur? Are there great natural fluctuations in abundance, or quality, other than those of depletion? Is it possible to foretell fluctuations? Stated differently, there is a strip of waters along the coast of California populated with the California sardine. We wish to know whether this population may become reduced by overfishing, or whether it may become periodically smaller or larger due to natural causes entirely aside from the effects of man's inroads. Moreover, we wish to foretell these changes, no matter what their cause.

To answer any of these questions, it requires a knowledge of the sardine population such as the student of vital statistics, if you please, has of the human population. Dr. Johan Hjort, in a lecture before the International Council for the Study of the Sea in 1907,² made this comparison very forcibly in the following words:

"To make my ideas clearer, I will proceed to draw a comparison between this fishery research and a science which is much more generally understood. I mean the science of vital statistics. In all exposition of the science of vital statistics, there are three prominent features which attract our chief consideration:

1. Birthrate.
2. Age-distribution.
3. Migration.

It is customary to study these questions by the help of what are called representative statistics. A certain number of individuals are selected, who are supposed to stand for the mass of the people, and attention is directed to them. We ascertain from this source their average length of life, their wanderings, their increase or decrease, and whether sickness, war, disaster, or emigration plays any appreciable part in reducing the population.

"It seems at first sight a bold suggestion to propose studying the fish supply on lines like these. A population can be counted; but, who knows how many fishes are in the sea? And yet it appears to me a project big with possibility, to regard the discoveries of fisheries research from a similar standpoint to what has been adopted in the science of vital statistics."

Accepting this conception of fishery research—and we must—the question arises: How can we, in the case of the sardine, secure proper representation? How should we "select the individuals" who are to "stand for the mass"? There are many billions of sardines in the

¹ W. F. Thompson: "The Proposed Investigation of the Sardine." California Fish and Game, Vol. VI, No. 1, pp. 10-12, Jan. 1920.

² Johan Hjort: "Fluctuations in the Great Fisheries of Northern Europe Viewed in the Light of Biological Research." Conseil Permanent pour l'Exploration de la Mer. Rapports et Procès-Verbaux des Réunions. Vol. XX, p. 11.

ocean, but the samples can only include a few thousands. Therefore, our representation must be small; very much smaller than any parallel drawn from the study of vital statistics. Also, the species is a pelagic one, wandering about for the most part on the surface of the seas in schools, highly selective in composition, which makes it much less probable that a few samples are representative than if the population were one with habits more conducive to homogeneity. Since it thus seems very questionable that a limited sampling of the sardine would be representative, a study of this phase is urgent.

The data taken during the initial season of the investigation, the winter of 1919-1920, have therefore been subjected to careful analysis in order to determine upon a system of sampling which shall be effective in providing proper representation and at the same time a minimum expenditure of effort.

In studying the questions of representation in sampling, it is evident that some criterion must be employed to distinguish between groups of individuals. It is also evident that this criterion should be one which can be collected and handled in large numbers and subjected to statistical procedure and analysis. Numerous criteria might be used: length, weight, color, age, sex, scale counts, fin-ray counts, etc. The first named has advantages which make it superior to the others for the present purpose. It is a character which may readily be determined for large numbers of fish, it is a magnitude which is readily subject to statistical analysis and is one which may be determined with a minimum of personal bias. For these reasons, it has been employed in the present study of sampling.

Data on the lengths of about one hundred fish were available for almost each day of the period covered. From this mass of data, six systems of sampling were taken as follows: alternate days, twice a week, weekly, twice a month, monthly, and a system patterned on the Norwegian spring herring investigation for the year 1917. As many as six trials were made of some of the systems.

When compared to the results of daily sampling, these trials brought forth the following facts: first, that no system was sufficiently random to accurately represent the population of sardines at large when judged by a rigid statistical method; second, that trials of monthly sampling and the trial based on the Norwegian investigation produced results which were directly contradictory of the daily systems and therefore utterly invalid for this investigation; and third, that sampling at least twice a week would be necessary to produce data which had a fair likelihood of representing the commercial catch with a reasonable degree of accuracy.

The results of the study have already been used as a guide for the sampling program in subsequent years. Publication of this study is now undertaken in order that it may contribute to the establishment of firmer foundation of the fisheries sciences. Details of the methods employed and the considerations involved follow:

ROUTINE OF FIELD WORK.

The services of one man only, the writer, being available for the investigation at Monterey, no elaborate system of experimental fishing was undertaken. By utilizing the supplies of fish brought in by the

General Plan.

commercial fishermen daily, it has been possible to secure a fairly thorough sampling of the sardine population, more thorough, no doubt, than could be secured by the limited number of successful hauls a scientific vessel could make; for, in the commercial fishery there are scores of vessels making hauls simultaneously in various parts of the bay, whereas a single boat scientifically directed could make only a few hauls, and these perforce in the same general locality.

Accordingly, the canneries were visited daily. Samples were taken from each of several catches of the commercial fishermen, at least five in number, if possible. These were taken as the fish were unloaded

Collection of Samples.

at the canneries. Utmost care was used to insure random sampling in all cases. To avoid the effect of a possible tendency for the large sardines to gravitate to the bottom, or vice versa, the samples were never taken from the very top or the very bottom of a load. The sample was scooped up at random from the receiving tank or flume in a bucket with a perforated bottom, and after the water had drained off, was weighed on a spring dial scale to the nearest ounce. Then the contained sardines were counted out and the empty bucket, with whatever debris happened to have been contained, was again weighed, securing a tare weight, from which the net weight of the sample could be calculated, which together with the number of sardines allows an average size determination.

When counting out, a number of specimens, usually twenty, were reserved from each sample. In order to make this choice as random as possible, they were taken by saving out each third or fourth fish, as the case might be, in order to get about twenty. These samples were taken to the laboratory, where they were measured, sexed and their maturity judged as nearly as possible.

Two measurements were taken on each sardine: The body length, measured from the tip of the snout to the base of the caudal fin as determined by the end of the silvery area on the sides of the caudal peduncle; and the total length, measured from the tip of the snout to the tips

Measurements.

of the caudal fin when in a position so that the outer edges of the fin were parallel to the longitudinal axis of the body. By using a measuring board,³ it was possible to measure quickly to the nearest millimeter.

Gross errors, such as reading the wrong ten millimeters, or ten centimeters, or recording the wrong number, were detected by the following special technique suggested by Mr. Thompson. It rests upon the fact

Detection of Errors.

that a fish of a given body length may be expected to have an appropriate total length. Due to variability in the length of the caudal fin, the total length would not be the same in every case, but would vary to either side of the mean, clustering about it in the manner of a normal frequency distribution. The standard deviation of that distribution can be calculated and knowing that the great bulk at least of the observations, 999 out of 1000, would normally fall

³ W. F. Thompson: "A Contribution to the Life History of the Pacific Herring." Rpt. British Columbia Comm'r. of Fisheries, 1916. The identical board used is figured on page 46.

within a range of six times the standard deviation, any observation which departs from the mean more than plus or minus three times the standard deviation, is not a normal one and has a thousand to one chance of being in error. Variations due to frayed caudal fin are included in this empirical determination (except those which were seriously broken, and hence discarded) and therefore are subject to the same test. In this way a variability index was determined for small, medium, and large sized sardines, the values for intermediate sizes interpolated, and a table prepared, showing the possible normal lengths for each body length. All of the measurements were then compared to this table and the doubtful ones discarded. This amounted to 28 out of the 7668 fish measured during the winter season of 1919-1920.

SIZE FLUCTUATIONS FROM DAY TO DAY.

The data thus collected give, in addition to the individual sizes, the material by which we may determine the mean or average size of fish present in the commercial catch on each day. Also, the means may be calculated on the basis of either weight or length.

Available Data.

In the case of the weights, the determination is upon about 270 individuals each day, and, in the case of the lengths on about 100 individuals each day. By comparing the two series it is possible to determine somewhat definitely whether the average weight on that number of fish gives substantially the same result as the average length on the lesser number of fish, in other words, whether the number reserved for measuring was sufficient for the purpose of showing fluctuations from day to day.

In determining the mean sizes, either the mean of the aggregate of the individuals may be used, or the mean of the means of the several samples. The former would be in the nature of a weighted average size, the latter would give each sample equal weight in determining the mean for the day. In order to discuss this question clearly a specific example will be considered. Considering January 3 for example, the following computation is made:

Sample	Number in sample	Sum lengths	Mean	Probable error of mean
136 -----	20	4624	231.2	2.7
137 -----	20	4210	210.5	1.9
138 -----	22	4572	207.8	3.4
139 -----	23	5213	226.7	2.8
140 -----	42	8518	202.8	.8
Totals -----	127	27,137	1079.0	
1. Mean = $\frac{27,137}{127} = 212.7$ mm.				
or				
2. Mean* = $\frac{1079.0}{5} = 215.8$ mm.				

The first method, that of dividing the sum of the lengths by the number of fish, gives an average size in which the largest samples have the greatest representation. The second method, that of taking the

mean of the mean sizes of each sample, gives each sample equal importance in determining the mean for the day. It may be said in favor of the former method that the larger samples in general should have a more accurate mean, but, on the other hand, each sample is equally likely to have come from a school or schools of fish which represent the population most accurately regardless of the accidental circumstances which caused the collector to take many or few fish from that load. The argument in favor of the first method seems to have somewhat less weight, for, as may be seen from the above computation the probable errors of the means are much less than the difference of the means of the several samples. The greatest probable error is 3.4 millimeters, while the difference between the samples is as great, as 28.4 millimeters. Also, sample No. 138, although it has more fish than either of the two previous samples has a probable error which is greater than either of the foregoing samples.⁴ This difference between the means of the samples seems to be due to a real difference in the population from which they came rather than a difference due to a chance error of sampling. Therefore, it seems best to give each sample equal value in determining the mean for the day; and, accordingly that method has been used in computing the mean length for each day. The resulting values are shown in table I for both mean weight and mean body length, and the graphs are shown in figure 1.

It is evident from these two curves that the mean weights of about 300 fish follow very closely the mean lengths of samples containing one-third as many, and that to show the fluctuations in average size from day to day, the measurements of one hundred fish daily furnish data quite as accurate for this purpose as the weights on three times as many.

Comparison of Weights and Lengths.

It may also be seen from these curves that the fluctuation during the season is of considerable magnitude, being from less than three ounces to almost eight ounces in average weight, and 190 to 255 millimeters in length. Moreover, these fluctuations do not appear to be entirely haphazard, for, besides a general tendency to get larger fish toward the

The Fluctuations.

end of the season there is some indication of a cycle of about a month during which the average size moves from minimum to maximum and then returns to the minimum again. The data are too fragmentary and the time period over which they extend is too short to show this very definitely; but, there can be no doubt that there are decided changes in the population of fish, and that they are not entirely random in character. The problem which faces us, in this study, is how best to sample this fishery in order to get a reliable picture of the average catch of commercial fishermen from year to year.

LENGTH FREQUENCY DISTRIBUTION OF SEASON'S DATA.

The composition of the sardine population may be studied in detail by means of the length measurements that were taken daily. Since the total lengths are subject to unreliability due to the frequently frayed

⁴ Probable error of the mean was calculated in the usual manner, the formula being:
Standard deviation

Probable error of the mean = $\frac{.6745}{\sqrt{\text{Number of items}}}$

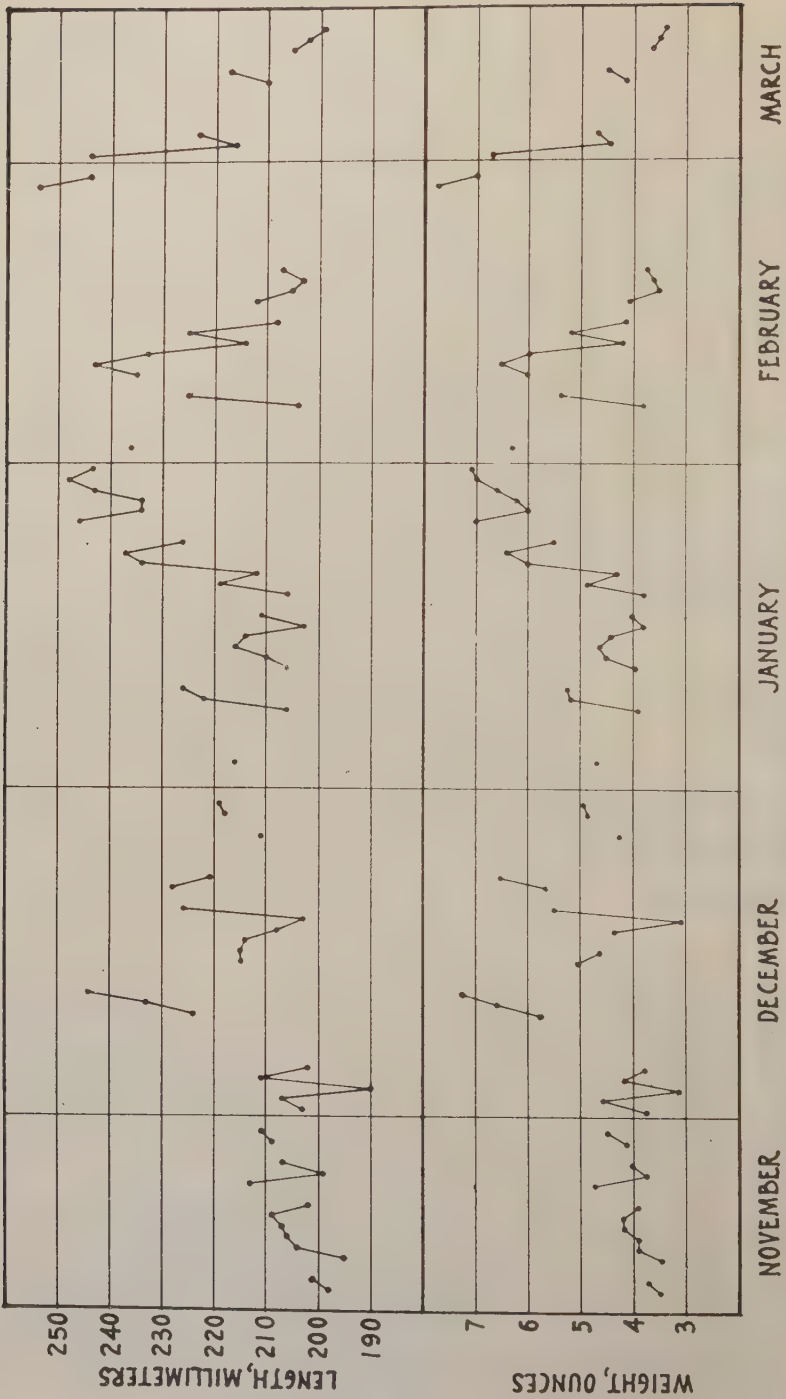


FIGURE 1. Historiogram of average lengths and average weights of sardines at Monterey, season of 1919-1920.

Discussion of Available Data.

condition of the caudal fin, the body length measurements have been used exclusively. A frequency distribution of all of the length measurements shows, roughly, the size composition of the population, or various populations of sardines which were caught by the commercial fishermen during the winter; but it is confused and probably biased due to the irregular sizes of the samples taken, and the total number of fish provided in each day's samples.

It may be noticed (see appendix table No. I) that the numbers of sardines measured each day during the early part of the winter were consistently less than later in the winter; and, by consulting the curves of average size in figure 1 we find that during the same early portion of the season the sardines averaged smaller in size. Hence, since through the mere accident of sampling, there were fewer fish taken during that time, the season's frequency distribution probably has a smaller proportion of the small sardines than were actually taken in the commercial catch. In other words, the small fish are under-represented.

Irregularities.

Similarly, the samples within one day, if they are not of the same size, may underrepresent some category of fish. If, say, the collector consistently tended to take more fish in a sample when the fish were small, which could easily be the case, the bias thus produced might be very significant.

We have sought to remove both of these objections as much as possible. The latter one, that of unequal sized samples within one day, was removed by discarding, at random, enough fish from the larger samples so as to make all of the samples on that

Treatment to Dis- count Irregularities.

day approximately equal in size. The numbers of fish left in each sample after this was done may be seen in the columns headed "Totals for day" in table II. The day-quotas were equalized by "weighting" each fish in a certain day's samples sufficiently to make the day's total of fish equivalent to one hundred. For instance, on November 14th there were 126 fish, therefore, each fish was treated by the factor $\frac{100}{126}$ giving each one a value of .79 instead of 1.00 upon entering the frequency distribution of the season. Similarly, on November 17th, where there were only 41 fish, each was given a value of $\frac{100}{41}$ or 2.44.

This is the same in effect as converting each separate day's frequency distribution into a percentage frequency⁶ and then adding the corresponding items of all of the day frequencies to make the season frequency curve.

In order to preserve the greatest possible amount of detail in the frequencies, the size classes were made exceedingly small, including only one millimeter each. This tends to make the distribution rather irregular. Also, it presents a somewhat false impression of accuracy, for, although the readings of length were made to the nearest millimeter, the variations in the position in which a sardine might lie on the measuring board and the variation in determining the exact point

⁶This is done by calculating the percentage of the fish in each size class to the total number in the frequency distribution; all of the size classes, thus computed, when added together equal 100 per cent.

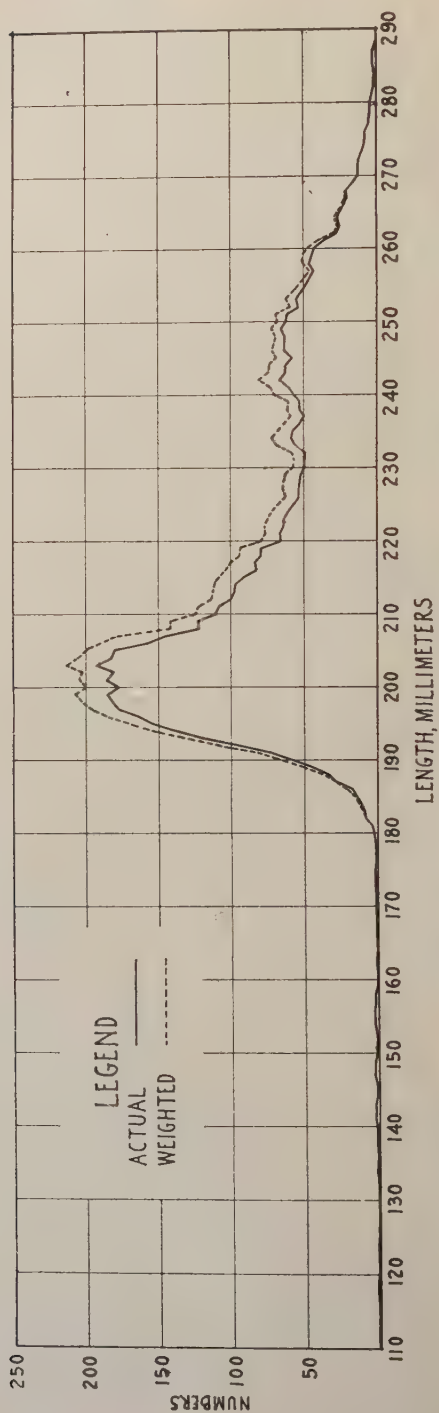


FIGURE 2. Frequency polygon of the lengths of all sardines taken in the regular sampling of the Monterey sardine investigation from November 14, 1919, to March 13, 1920.

of the base of the caudal fin may account for a variation of a millimeter either way from the actual length read. By "smoothing" the distribution with a moving "average" of three, which is really spreading each item over three adjoining size classes, both a "smoothing off" of the irregularities and discounting of the inaccuracies of measurement is accomplished.

The resulting frequency distribution is tabulated in table III and graphically presented as a frequency polygon in figure 2. Both the actual and the weighted frequency curves are given in order to see the effect of weighting.

The weighted and unweighted data produce remarkably similar results. This may possibly be due to the fact that the two hypothetical biases mentioned above, that of underrepresentation of the smaller fish due to small day-quotas early in the season, and overrepresentation of the smaller fish by a tendency to take larger samples of them throughout the whole season, tend to counteract each other in the long run. Nevertheless, the data as weighted should be the fairer representation of the population sampled and therefore have been used wherever possible in this analysis.

It will be noticed in the frequency distribution that, while most of the fish fall in a group above 178 millimeters in length, there is a marked scattering of the smaller sardines down to 120 millimeters in length. This very diffuse scattering, covering as it does, about one-third of the entire range of sizes, is clearly not a normal distribution. It is due to the presence of a group or groups of small sardines ranging up to 178 millimeters in length which the fishermen do not take to a great extent. There is some fairly clear evidence on the cause and manner of this "selection." During practically all of the period covered by this investigation the demand of the canners was for "pound-oval sardines", meaning sardines of fairly large size, roughly, above 17 or 18 centimeters in length. On November 17th, however, one cannery demanded "quarter-oils", that is, sardines 12 to 16 centimeters in length. There were four samples taken on that day. Two of them were from catches made for the general pound-oval canning, and two from catches made in response to the quarter-oil demand. Measurements of fish in these samples are shown in the following table:

Body lengths, millimeters	"Quarter-oil" catches		"Pound-oval" catches	
	Sample No. 13	Sample No. 14	Sample No. 15	Sample No. 16
125-129.....	3	2		
130.....	7	15		
135.....	7	10		
140.....	4	7	1	
145.....	6	5		1
150.....	7	5		1
155.....	2	4		
160.....	1	1		
165.....			1	
170.....			1	
180.....		1	1	
185.....			2	1
190.....			6	5
195.....			3	4
200.....			4	5
205.....			2	1
210-214.....				2

From this it is evident that upon occasion the fishermen met the demand in a very efficient way, almost all of the sardines in each case being of suitable size for the style of pack intended. In all cases the fishermen used the same style of nets and gear, the difference being in part the localities chosen for fishing, and in part the schools selected when making the hauls. Mr. W. L. Scofield, who has made many trips with the sardine fishermen, assures me that during the season 1920-21 they had very little difficulty in distinguishing between the "large" and the "small" sardines when they were cruising around in search of suitable fish. Those of smaller size which do appear in the regular catches are accidental stragglers, indicating probably the varying degree of accuracy with which the fisherman chooses his schools rather than the relative abundance of these small sardines.

Since there is no likelihood of representative sampling of the small sardines, this study has been restricted to the group of large sardines. From figure 2, and table III, it is seen that this group has a natural lower limit at about 178 mm. Accordingly, all individuals under 178 mm. in body length have been discarded from the samples. This leaves the number of fish in each day's samples as shown in the column headed "Total above 178 mm." in table II. It is seen that the equality of the various day-quotas is again destroyed, so on the basis of these new values, the frequency has again been treated to make each day of equal importance in the total frequency as before. The result is shown in table III and the solid-line polygon in figure 4 and constitutes the "standard" frequency distribution.

Recapitulating, the "standard" frequency is a picture of the lengths of the sardines in Monterey Bay as caught by the commercial fishermen every day throughout the period of time covered, each day being represented by an equal number of fish made up of from one to six boat-samples a day, each of these boat-samples being of catches containing from one to about eight hauls of sardines. This "standard" system of sampling will be used as the basis for comparing the merits of other "trial" systems.

OTHER SYSTEMS OF SAMPLING.

It is natural to seek for precedent when considering the question of sampling. The investigations on the herring along the coast of Norway probably resemble the California sardine investigations most closely in respect to the species dealt with and the method of study, which is that of representative sampling. The remarkable results attending these herring investigations make the emulation of such sampling methods eminently desirable. It is their practice to take about a dozen fairly large samples, about 200 to 400 individuals in each, at various times during the season, basing their opinion of the population on these samples. It is obvious that the Norwegian system, if feasible, would be a much greater economy than a daily system; and, although there is no direct proof that their system secures correct representation, according to Hjort its sufficiency

The Norwegian Herring Investi- gations.

is indicated by the consistent results obtained in the various samples and from year to year.⁷

In the present investigation the data for a number of years are not available, and, since the samples seem more variable than consistent, the merits of the sampling can not be judged by that criterion. It is possible, however, to try a system of sampling resembling theirs very closely and see how the resulting frequency distribution differs from the "standard" frequency distribution.

Comparison of Norwegian Herring Investigation With California Sardine Investigation.

In making this comparison, the researches on the Norwegian spring herring of 1917⁸ furnish a good example. Since the seasons do not cover the same period it is not possible to take identical dates in each system. In figure 3 are shown the dates of the two seasons with the comparable samples indicated.

In order that the two systems of sampling may resemble each other most completely, the fish in the sardine samples have been treated with a weighting factor to make them the equivalent in number to the respective samples in the herring investigation. Thus, on the dates of December 17 and January 31 there are 82 sardines and 228 herring respectively; accordingly each sardine was treated with the factor $\frac{228}{82}$ or 2.78 when it was assigned to the frequency distribution, and

so on with the other comparable dates. In this way the peculiarities in the size of samples and the dates upon which they were taken in the herring investigation are approximated in the sardine investigation. The resulting frequency is shown by the broken-line polygon in figure 4 compared with the standard frequency. In this and all subsequent graphs the frequencies in both distributions have been converted to percentages for the purpose of comparison.

The difference in the two distributions is strikingly apparent. In the standard frequency the sardines around 200 millimeters in length strongly dominate the population; in the trial system, the group around 250 millimeters is slightly dominant. The cause for this disparity is not difficult to find. The fish in the standard distribution were taken from all parts of the season. Those in the trial distribution came mostly from a small portion of the season when the sardines averaged large in size.

In order that the significance of such a discrepancy may be understood, it should be remembered that the sardines of 250 millimeters length may be several years older than those of 200 millimeters length. The picture shown in the trial curve is that of a population in which the aged fish are most abundant, while the population as more truly pictured in the standard curve is one in which the recently matured individuals strongly predominate.

A factor in this difference which has not been considered is the reduction in the actual numbers of individuals which enter the dis-

⁷Johan Hjort: "Fluctuations of the Great Fisheries of Northern Europe." Rapp. et Proc. Verb. Vol. XX, pp. 28-31.

⁸Einar Lea: "Sildenundersokelser 1916-17." Norges Fiskerier for 1917, Heft 1, p. 45.

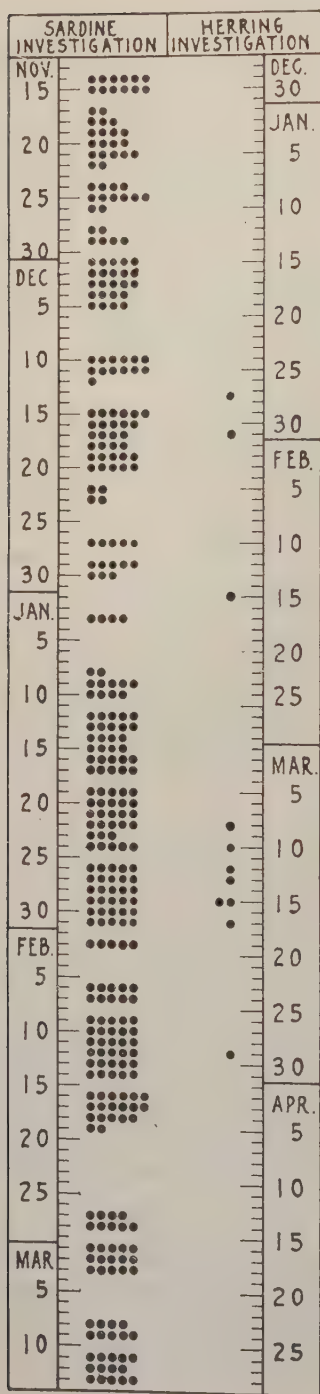


FIGURE 3. The sampling of the sardine investigation at Monterey 1919-1920, compared to the Norwegian herring investigation of 1917. Each dot represents one sample.

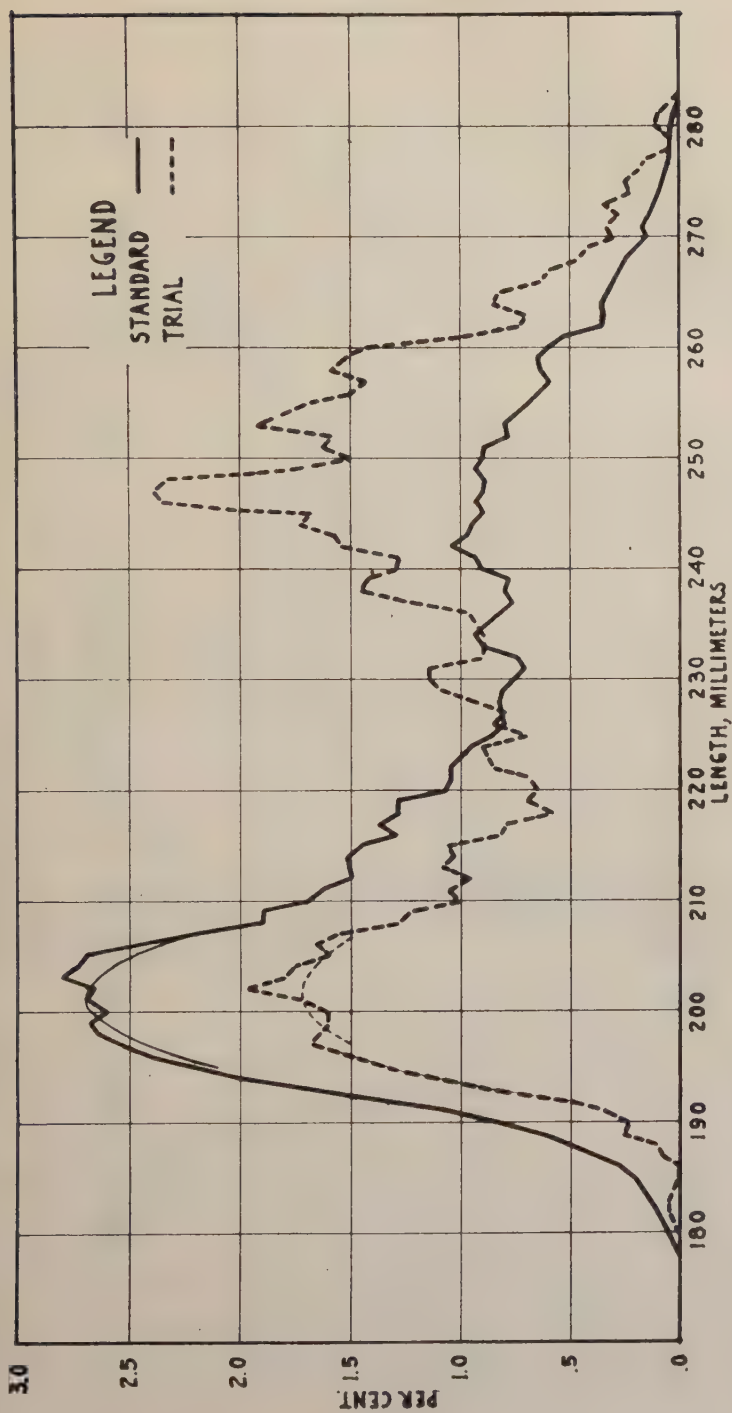


FIGURE 4. The frequency polygon of lengths obtained in the trial of sampling based on the methods used in the investigation of the Norwegian spring herring of 1917, compared to the standard frequency polygon of lengths obtained in the sardine investigation at Monterey, 1919-1920.

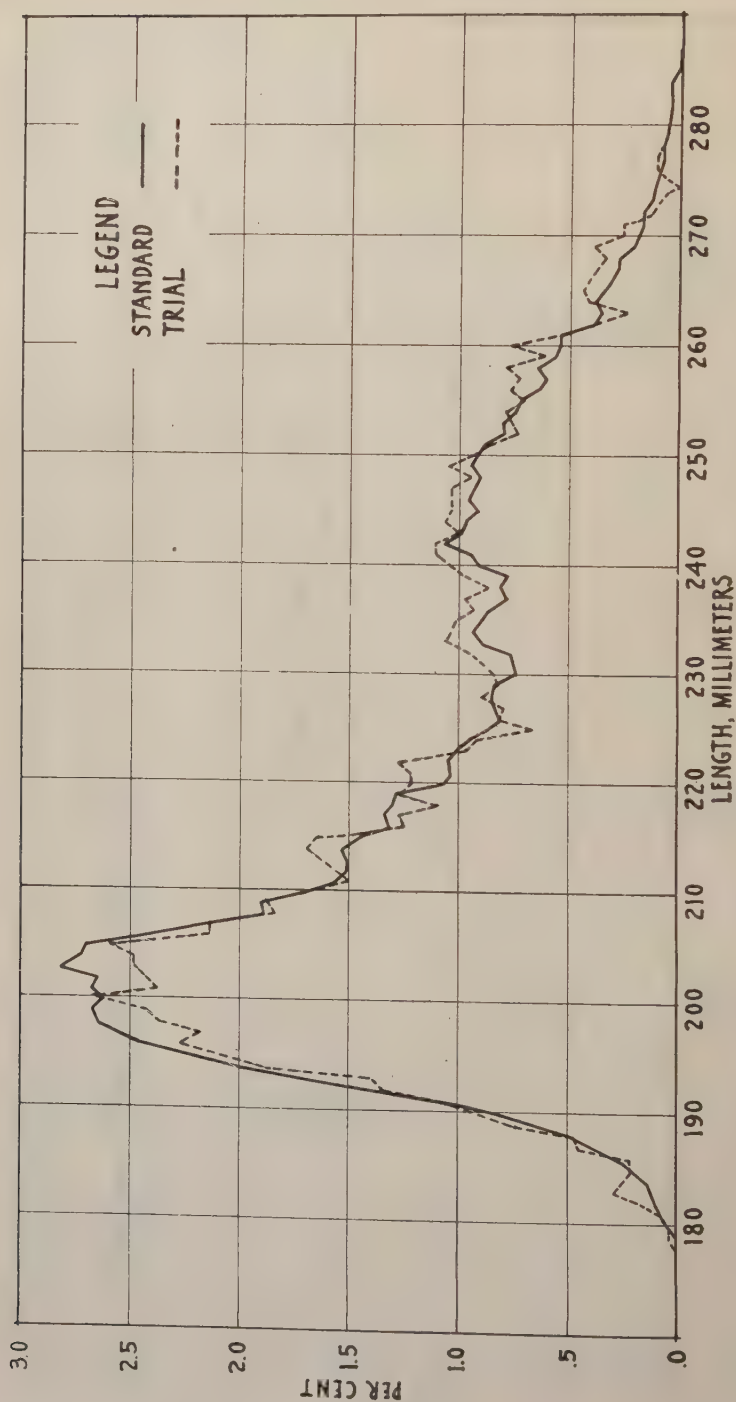


FIGURE 5. The frequency polygon of lengths obtained in the trial sampling of fifteen fish per day compared to the standard frequency polygon of lengths.

tribution. In the standard distribution there are actually 6750 individuals, while in the trial distribution there are only 1031 individuals. In order to see the effect of such a reduction in numbers when the manner of taking samples is unchanged, a frequency has been compiled by taking 15 fish from each day's samples in a random manner. The resulting frequency distribution is compared to the standard system in figure 5.

As might be expected, the contour of the trial frequency polygon is more irregular than that of the standard frequency, but otherwise it is substantially similar. Evidently no such striking dissimilarities as are found in the trial based on the herring sampling system could be due to the lesser numbers of individuals. They must be due to the difference in the method of sampling.

Having seen that the ordinary fortuitous system of sampling would be unreliable in this investigation, some other plan must be devised. The plan should be economical and practical, and should assemble data

Other Trial Systems. on the sardine population which would be sufficiently reliable to furnish comparably representative statistics from year to year. To this end a number of trials of sampling have been made. They consist of systems by which the collections of samples are made on alternate days, twice a week, weekly, fortnightly, and monthly, using in each case except the last, the data weighted so as to make the equivalent of 100 fish on each day that samples were taken.

Two trials of sampling on alternate days were made. In one, samples were taken on Mondays, Wednesdays, and Fridays; in the other, on Tuesdays, Thursdays, and Saturdays. The frequency polygon resulting from the latter trial is shown in figure

Trials of Sampling on Alternate Days. 6. Since the choice of sampling days in this case results in all the data missed in one system being included in the other system the frequencies of the two trials are really complementary halves of the whole season's data, and, as might be expected, neither one of them differs much from the standard polygon.

Of the semiweekly systems, three trials were made. In figure 7 is shown a polygon of the system of sampling which seems to be the one best representative of such trials, namely, the one which neither departs from the standard polygon most widely, nor resembles it most closely.

Trials of Sampling Twice a Week. In the case of the trials of weekly sampling it was found that using the fixed day of the week, say Mondays, led to the occurrence of large gaps in the historic sequence of samples, for there were frequent instances when data on Mondays were lacking. Since the intention in those trials is to have uniform time intervals between the samples, such gaps would defeat the purpose. So, in such

Trials of Sampling Weekly. cases the nearest subsequent date on which data were available was taken. This plan is quite feasible in practice. The observer might plan to take samples on a certain day each week, and whenever it was

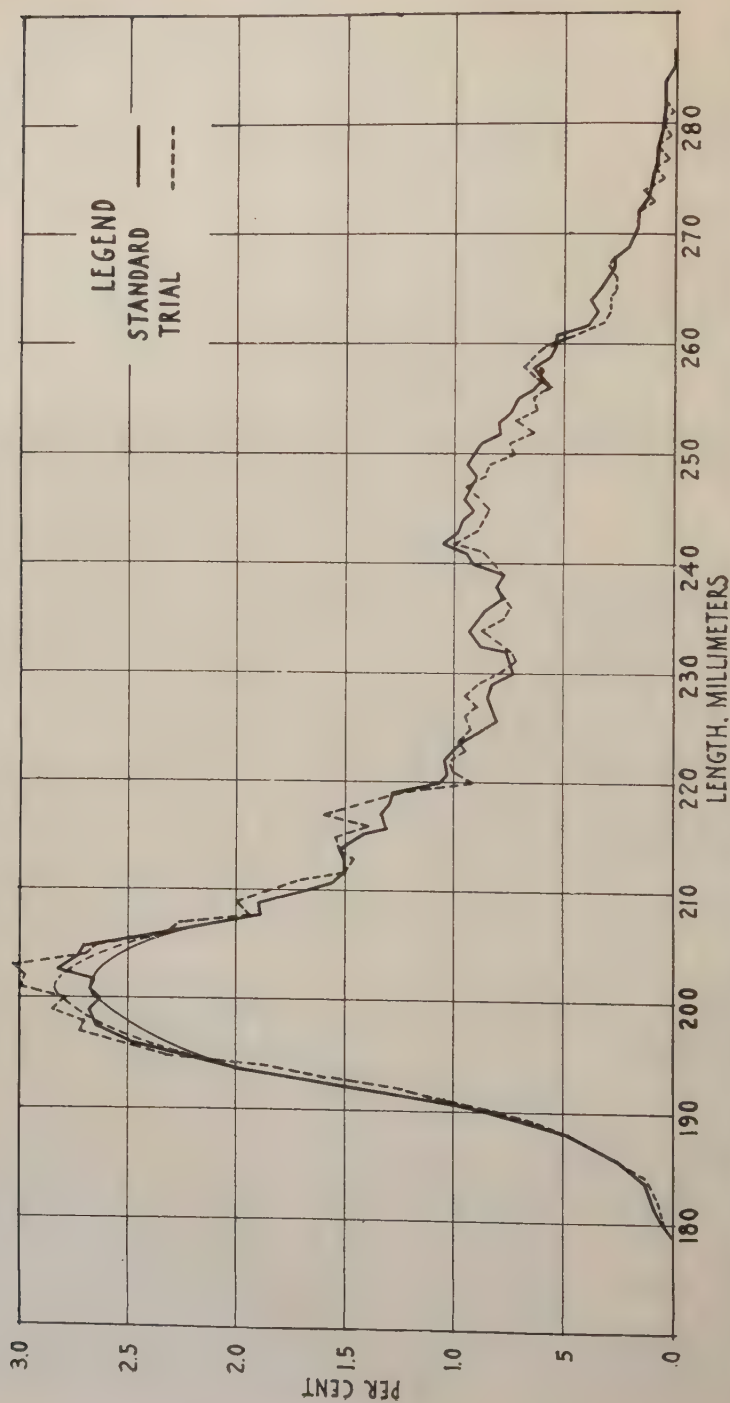


FIGURE 6. The frequency polygon of lengths obtained in trial B of sampling on alternate days compared to the standard frequency polygon of lengths.

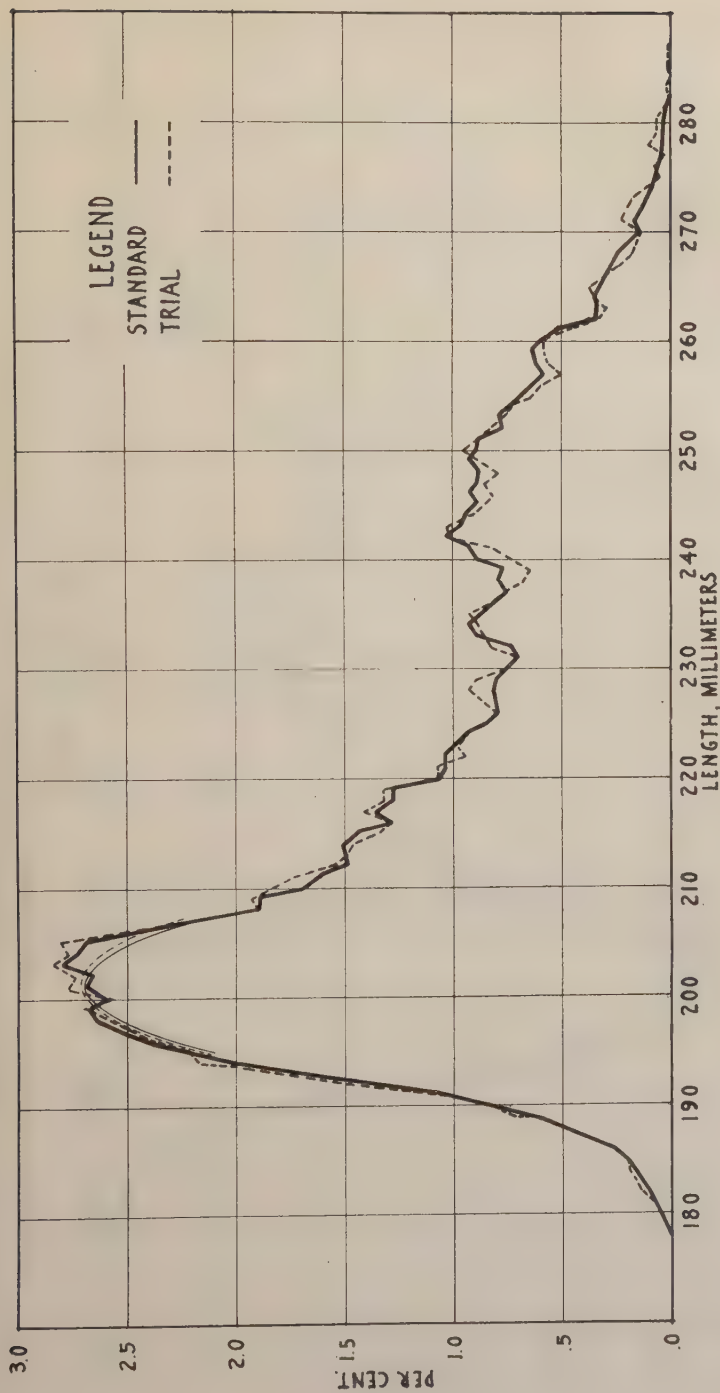


FIGURE 7. The frequency polygon of lengths obtained in trial B of semi-weekly sampling compared to the standard frequency polygon of lengths.

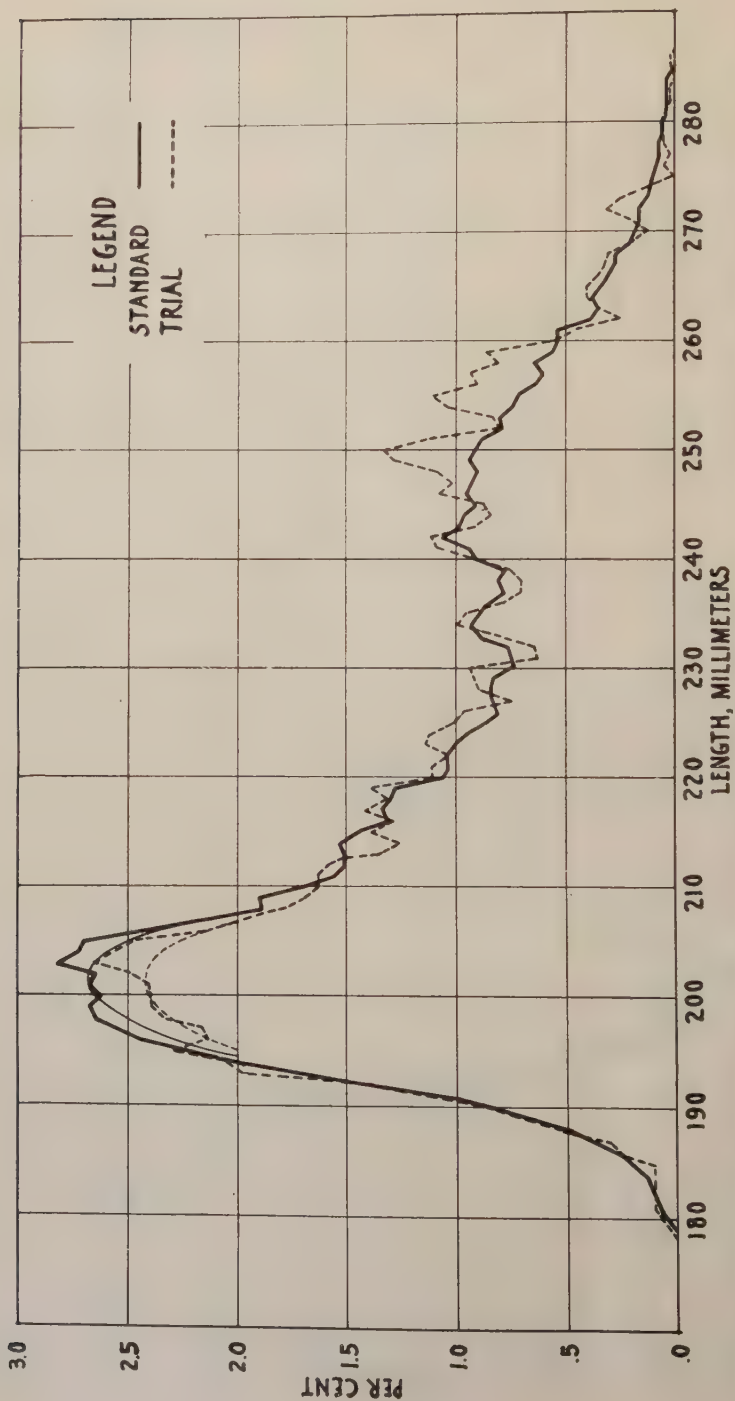


FIGURE 8. The frequency polygon of lengths obtained in trial F of weekly sampling compared to the standard frequency polygon of length this.

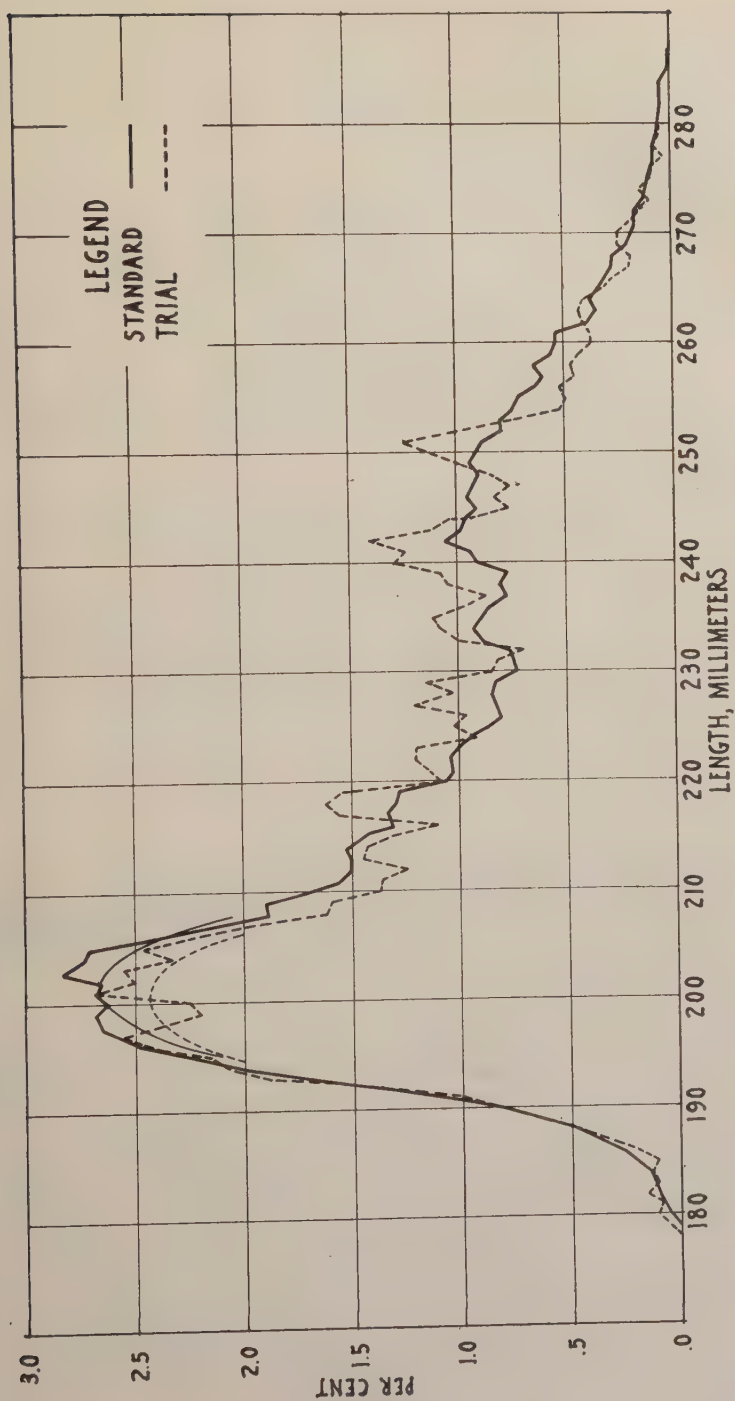


FIGURE 9. The frequency polygon of lengths obtained in trial D of sampling twice a month compared to the standard frequency polygon of lengths.

impossible to get them on the regular day they could be sought on every subsequent day until they were procured. On this basis six trials of weekly sampling were made, one on each day of the week. The polygon of an average one of these trials (F) is shown in figure 8. Among the six trials there was one which resembled the standard frequency very closely and several which departed from the standard frequency to a greater extent than the trial F.

In the case of the trials of fortnightly sampling, it was necessary to use two adjoining days at each fortnightly interval. for, in using only one day's data, the number of fish taken would have been too few to give a valid comparison. In practice such a system might be approximated by taking 200 fish on one day, or 100 on each of the two successive days at fortnightly intervals. As in the weekly trials, the lacking day was represented by the nearest subsequent day, and six trials were made. In figure 9 is shown the frequency polygon of the trial which seems midway between the extremes of the worst and best representation.

The trials of monthly sampling required similar methods further modified. It was desired to simulate a routine in which samples should be taken on a fixed day of each month, the samples to be sufficiently large to provide more than a thousand fish for the season. To do this a group of five consecutive days was chosen in each month. Taking the data in each group percentage frequencies were compiled which, when added together, size-class by size-class, formed a season curve, in which each month was given equal representation. In practice 500 individuals might be taken on one day or several successive days each month. Two trials of the monthly systems were made and are shown in figure 10.

COMPARISON OF THE VARIOUS SYSTEMS OF SAMPLING.

The dates used in all of the trials may be found in table V; inspection of the figures shows that there is increasing disparity between the results of the trial and the standard systems as we proceed from the alternate-day trials to the monthly trials, and while the former differ so slightly as to be negligible, the latter differ so widely as to seem to represent entirely different populations. Moreover, many of the trials which are not here presented showed even greater discrepancies. Considered altogether, they form an almost continuously intergrading series between the near perfection of the alternate-day trials and the monthly trials. Plainly, the alternate-day trials furnish a fairly good representation and conversely, the monthly trials furnish very faulty representations of the sardine population. The question arises: Where is the line crossed between sufficiency and insufficiency in sampling?

A Statistical
Criterion Based on
the Theory of
Probabilities.

formula:

Biometricians furnish a means of judging the probability of two given frequency distributions having come from the same population. The formula given by Karl Pearson is probably the best adapted to this problem. His method is to calculate the argument χ^2 by means of the

$$\chi^2 = S \left\{ \frac{NN^1 \left(\frac{f_p}{N} - \frac{f_p^1}{N^1} \right)^2}{f_p + f_p^1} \right\}$$

where f_p is the frequency in the size-class p of one frequency distribution and f_p^1 the values in the size-class p of the other frequency distribution, and N and N^1 are the total number of items in the respective frequencies (S is the summation of these values calculated for each size-class). Quoting Pearson, "The probability P that the observed or a greater divergence between the two series would arise from sampling the same population is obtained by determining P from χ^2 by my method of testing goodness of fit." The shortest method of actually determining P is by aid of Palin Elderton's tables for P with the argument χ^2 .⁹

In the same paper (page 85) he says that this method since it is "based on the theory of sampling, calls for no hypothesis as to the general theory of frequency. It takes the observed distributions and measures the probability that both are samples from a large population. The population may be homogeneous or heterogeneous; provided the samples are truly random samples we obtain a measure of probability of their common origin."

In applying this formula to the problem in hand, this conception of the conditions may make the application clear. We have a group of individuals which make up the "standard" frequency distribution. This may be considered a "universe" composed of various populations, these populations being the various samples which contributed individuals to the standard distribution. Each trial system of sampling includes a number of separate samples or populations. By comparing one of these trial systems with all of the samples or populations of the standard frequency which this particular trial chanced to miss, on the basis of this formula, we may determine whether the trial distribution resembles the distribution it misses closely enough to indicate that both of the distributions come from the same large population. If that is the case we may consider the system as suitable as the standard itself.

Accordingly, the χ^2 values and the corresponding P values for each of the trial systems have been computed. In order to approach the experimental conditions upon which the formula was based, the actual instead of the weighted frequencies were used, and, to facilitate the calculations, the frequencies were grouped in five-millimeter classes instead of the one-millimeter groups heretofore used. The "clubbing" of the frequencies at the extremes of the distribution was done as recommended by Pearson,¹⁰ in order to avoid the discrepancies due to the reduced numbers in the "tails" of the frequency distribution.

As a "control," this argument was computed on the series of fifteen fish daily, which gives a picture of the result of taking a random sample directly from the standard distribution. It contains a few over a thousand fish and is thus comparable to the amount to which the weekly, fortnightly, and monthly systems were reduced. The value

⁹Karl Pearson: "On the Probability that Two Independent Distributions of Frequency are Really Samples of the Same Population, with Special Reference to the Recent Work on the Identity of Trypanosome Strains." *Biometrika* Vol. X, 1914, p. 92.

¹⁰Karl Pearson: "Tables for Statisticians and Biometricians," Cambridge, 1914.

of P for this curve may serve as the basis for comparison of the trials. The P value is somewhat inaccurate, due to a slight selection occurring in this way: t being the total number of fish for the day, $t-15$ is the residue after we have taken our fifteen fish a day, and is the population with which the frequency of fifteen per day is compared. But, since t varies from day to day, being under a hundred most of the early part of the season, $t-15$ also will vary, so that while the series of fifteen a day gives an equal representation, the $t-15$ series gives unequal representation during the season. This inequality would tend to make P smaller than it should be. With this reservation in mind the P value for this series may be used for comparison.

The result of the calculation on this control is that P equals .318, meaning that, roughly, the chances are one in three that the two series, t and $t-15$, are from the same population. Or, stated a little differently, three out of every ten samples taken from the same population would differ as much from each other as do these two frequencies. As we should expect, the value is a little lower than would ordinarily be the case.

The P values obtained from each trial system compared to the population missed by that trial are as listed in the following table:

<i>Systems</i>	<i>Trials</i>					
	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>E</i>	<i>F</i>
Fifteen fish daily-----	.3184					
Sampling alternate days-----	.0631	.0631				
Sampling twice a week-----	.0001	.0223	.2950			
Sampling weekly-----	.0000	.7441	.0142	.0075	.0880	.0371
Sampling fortnightly-----	.0000	.4039	.0016	.0259	.0344	.2960
Sampling monthly-----	.0000	.0000				
As the herring investigation-----	.0000					

The most striking feature of the results shown in this table is the lack of harmony. One would expect to find a constantly decreasing probability value as sampling proceeds at increasing intervals from the alternate-day sampling to the monthly sampling. On the contrary, the table of probability values shows a rather poor probability of 6.3 in 100 in alternate-day sampling, a range of one in ten thousand to three in ten in the semiweekly sampling, a range of from less than one in ten thousand to seven in ten in the weekly sampling, and so on, until a zero probability in the monthly sampling.

Upon careful scrutiny of the conditions of this analysis and the experimental conditions required in the application of the formula as developed by Pearson, it would seem that the most reasonable explanation of these rather incoherent results would lie in the fact that the experimental conditions required by the formula, namely that the sampling be truly random, is not attained in the case of the present sampling of the sardine population. In reviewing the conditions of the sampling carefully step by step, this group of facts may be emphasized; referring to the explanation of routine methods in the collection of samples it may confidently be assumed that the choice of a sample from the boat load of sardines is truly random; referring to the methods of fishing, the catch of sardines made by the cast of the net into or around a school of sardines is truly random except that schools of fish composed mainly of individuals under eighteen centimeters in length are avoided; but it may not be assumed that the

assemblage of sardines in a school is truly random. In this last point, I believe, lies the cause for the inconsistent probability values. There is reason to believe that the sardines school in the various localities and strata of water largely according to size. Such a phenomenon is described by Thompson in the case of the Pacific herring.¹¹ That the same thing holds true in the case of the sardine is a subject for further investigation and if this is the case, it is clearly apparent that the unit of variability is the school, not the individual. Since the entire probability analysis is on the basis of randomly selected individuals, it cannot be considered justly applicable to this problem.

With the sardines carrying on their own selection into schools, it can not be hoped that validity of sampling may be determined on the

**Practical Criteria
of Effectiveness of
Systems of Sampling.**

basis of established statistical methods based on the random selection of individuals. This need not, however, preclude the investigation of the sardine by representative sampling. The investigation is pointed toward definite ends, consisting of the discovery of certain biological facts, principal among which at the present time is the matter of growth as indicated by the positions of the modes, and the relative numbers of sardines produced each year, as indicated by the relative numerical importance of the modes.

First the value of the data presented by the various sampling trials in locating the positions of the modes will be scrutinized. Other studies of the California sardine indicate little growth movement by the modes

Location of Modes.

during the winter season. This being the case, the season's frequency may be used in its entirety, thereby allowing a maximum number for comparison. Again there is recourse to the standard frequency and all of the trial frequencies (figures 4 to 10). In them, two principal groups of fish are noted, one of them composed of individuals between 178 and about 230 millimeters in length, the other of sardines larger than this. This first group has a very distinct and unmistakable mode somewhere near 200 millimeters, which may be used in the study of the position of the modes in various trial systems.

It will be noted that the frequency polygon is so irregular in the vicinity of the mode that it is difficult to say just where the point of greatest frequency in the population really is. Since the multimodal nature of the frequency prevents the use of curve-fitting methods employed in determining the mode of a normal frequency curve, and since a smoothing of the values by inspection, even by means of the cumulative frequency, would allow of personal bias to enter, the method of smoothing this mode by the impartially mathematical method of moving averages was used. All of the frequencies were already smoothed by a moving average of three, in addition to this they were smoothed by a moving average of five, and again by a moving average of seven. All curves were treated alike and the results are shown by the fine curved lines in the graphs.

The smoothed curve of the standard frequency shows the highest point between 201 and 202 millimeters, about 201.5 millimeters. This is most probably the location of the mode in the population at large

¹¹W. F. Thompson. "A Contribution to the Life-history of the Pacific Herring; Its Bearing on the Condition and Future of the Fishery." Report of the British Columbia Commissioner of Fisheries, 1916, p. 47.

and will be so considered for the present purposes. In a similar way the modes as shown by each trial system of sampling have been determined. They are compared in the following table:

	Location of mode	Difference from standard	Extreme difference from standard
Standard Curve.....	201.5		
Alternate day sampling:			
Trial A	202.0	.5	
B	201.0	.5	.5
Twice a week sampling:			
Trial A	202.5	1.0	
B	202.0	.5	
C	201.5	0.0	1.0
Weekly sampling:			
Trial A	202.0	.5	
B	201.0	.5	
C	202.0	.5	
D	203.0	1.5	
E	203.0	1.5	
F	202.0	.5	1.5
Twice a month sampling:			
Trial A	201.5	0.0	
B	202.0	.5	
C	201.5	0.0	
D	201.0	.5	
E	203.5	2.0	
F	202.0	.5	2.0
Monthly sampling:			
Trial A	200.0	1.5	
B	206.0	4.5	4.5
Herring Investigation.....	202.0	.5	

This shows that there is an increasing difference in the positions of the modes of the trial curves as compared to that in the standard frequency, meaning that the risk of the mode being removed from its true position grows constantly greater as the interval between the taking of samples is lengthened.

The practical significance of such differences in the location of modes depends upon the conclusions which are to be drawn from the position of any distinct mode as compared from year to year. The analysis of data for years subsequent to the one under consideration has shown that there is a significant progression of this particular mode amounting to approximately one centimeter. This being the case, if the position of this mode in one year is to be compared to its position the next year and so on, the accuracy of determination of the position should be within a small percentage of one centimeter, which is the amount of its progression from year to year. For example, an error of .5 millimeter would constitute a 5 per cent error in the determination of the

progression of the mode, a 1.5 millimeter error would constitute a 15 per cent error, and so on. The determination of error so made is very rough indeed, but the argument seems to indicate that if we wish an accuracy of 10 per cent in determining the movement of this mode from year to year, the sampling must be as frequent as twice a week.

The position of the mode in the large fish is so problematical as to defy investigation without more data. It probably is composed of a mixture of a number of minor modes, and its position depends more upon the relative dominance of one over the others than upon anything else.

Equally, if not much more important than the location of the modes, is the relative number of individuals in the groups marked by the respective modes. It is the means of judging the comparative success of each spawning season. This promises to be one of the most significant phenomena in the fishery, influencing the sizes and abundance of the sardines more than all other things combined. Besides being important to the industry, it is of utmost importance in the detection of depletion. No effort should be spared to make the understanding of this phenomenon as clear as possible.

A most ideal way of handling the situation would be to determine the relative abundance of each year class, but, not knowing the age of the individual this is impossible. It is possible, however, to distinguish two principal groups in the population, those below 230 millimeters and those above that size. Each group may be composed of a number of year classes, but that need not invalidate their significance in this study of sampling. Each trial system may be examined to see what success it has in showing us the correct proportion of these two groups. An error in correctly representing the relative numbers of individuals in these two groups must entail an equal or greater error in representing one or the other of the age groups contributing to the size group.

In the standard frequency 4750 or .712 of the sardines were below 230 millimeters in length. This determination is of course not absolutely accurate. The proportion of fish below 230 millimeters in the population at large (considering only those longer than 178 millimeters) is undoubtedly somewhat different; but, this determination, based on samples taken daily, must be more nearly accurate than any in the trial systems in which samples were taken less often. In fact, the trial systems are really samples taken from the population of the standard system. Regarding them as such, their defects in representing the standard population may be evaluated. And, if it were found that they did not represent the population shown in the standard frequency they would have even less chance of representing the population at large. In the following table are shown the data upon which judgment as to the comparative merits of the trial systems may be made:

System of sampling		Proportion of fish under 230 mm. length	Difference of this proportion from standard curve	Standard deviation of the proportion	Observed difference divided by the standard deviation
100 fish daily (the standard)		.712			
15 fish daily-----		.683	.029	.0140	2.07
100 fish on alternate days---	(A)	.694	.018	.0080	2.25
	(B)	.730	.018	.0077	2.34
100 fish twice a week-----	(A)	.696	.016	.0089	1.80
	(B)	.725	.013	.0084	1.55
	(C)	.733	.021	.0086	2.44
100 fish weekly-----	(A)	.643	.069	.0127	5.43
	(B)	.714	.002	.0116	.17
	(C)	.749	.037	.0115	3.22
	(D)	.733	.021	.0118	1.81
	(E)	.706	.006	.0118	.51
	(F)	.683	.029	.0117	2.48
100 fish twice a month-----	(A)	.649	.063	.0121	5.21
	(B)	.709	.003	.0115	.26
	(C)	.693	.019	.0116	1.64
	(D)	.692	.020	.0121	1.65
	(E)	.754	.042	.0118	3.56
	(F)	.664	.048	.0119	4.03
About 400 fish once a month	(A)	.539	.173	.0074	23.40
	(B)	.908	.196	.0141	13.90
Sampling as in herring investigation-----		.457	.255	.0155	16.40

In the standard frequency distribution 4750 sardines were below 230 millimeters in length. This is .712 of the total number in the distribution and may be considered as the portion in the sardine population at large (disregarding those less than 178 millimeters in length), which are of those lengths. The trial samplings should approach this same proportion excepting for slight differences which might be expected under the conditions of "simple sampling." The observed proportions in each trial are shown in the first column of the above table, and the difference between these proportions and the standard proportion is shown in the second column. According to the theory of simple sampling as given by Yule¹² these observed differences should be less than three times their standard deviation. He says (p. 266) "We know roughly that the great bulk at least of the fluctuations (held to be 999 out of 1000 by some statisticians) of sampling lie within a range of a plus or minus three times the standard deviation; and if an observed difference from a theoretical result exceeds these limits it can not be ascribed to a fluctuation of simple sampling." The standard deviations are calculated by the formula:

$$\text{Standard deviation} = \sqrt{\frac{p q}{n}}$$

Where p equals the proportion of fish 230 millimeters or less in length and q equals the remainder, and n equals the entire number in the distribution. Thus in the alternate-day trial A

$$\text{Standard deviation} = \sqrt{\frac{.694 \times .306}{3309}} = .0080$$

¹² J. U. Yule: "Introduction to the Theory of Statistics," London, 1922, Chapter XIII.

The values thus calculated are shown in column three. Wherever the observed difference between the standard and the trial determinations exceeds these standard deviations by more than three times the latter, the differences are not likely to be due to the fluctuations of random sampling. In column four the observed differences are divided by the standard deviation. It may be concluded that wherever these values are greater than three there is only one chance in a thousand that the trial frequency represents the same population as does the standard frequency. This shows that in all of the trials up to the weekly systems, the differences lie within the possible error of fluctuation (3 sigma) but in the weekly system two out of the six are plainly beyond the limits of chance fluctuation, in the fortnightly, three out of six are, and both of the monthly trials as well as the system patterned on the European Herring Investigation are far outside the bounds of possible sampling fluctuations. Since the C trial of semiweekly sampling approaches perilously near three sigma, we would hesitate to recommend any less frequent system of sampling, as providing a thoroughly representative ratio of the two groups here considered.

Since this again is a theoretical consideration, it would be well to consider it in a more practical light, for possibly a little selection may be allowable without invalidating the data for our purposes. It seems to be a matter of what percentage the error is of the group examined. In the following table there are listed the proportions observed in each trial, their difference from that observed in the standard frequency, and the percentage of error in actual individuals which these differences represent:

System		Ratio of fish below 230 mm. to fish above 230 mm.	Difference from ratio in standard curve	Per cent error of 178-230 group	Per cent error of 230-286 group
Standard	-----	.712 : .288	---	---	---
Alternate days	A	.694 : .306	.018	2.5	6.3
	B	.730 : .270	.018	2.5	6.3
Semi-weekly	A	.696 : .304	.016	2.2	5.6
	B	.725 : .275	.013	1.8	4.5
	C	.733 : .217	.021	2.9	7.3
Weekly	A	.643 : .357	.069	9.7	23.0
	B	.714 : .286	.002	.3	.7
	C	.749 : .251	.037	5.2	12.8
	D	.733 : .267	.021	2.9	7.3
	E	.706 : .294	.006	.8	2.1
	F	.683 : .317	.029	4.1	9.7
Fortnightly	A	.649 : .351	.063	8.8	21.9
	B	.709 : .291	.003	.4	1.0
	C	.693 : .307	.019	2.7	5.6
	D	.692 : .308	.020	2.8	7.0
	E	.754 : .246	.042	5.9	14.6
	F	.664 : .336	.048	6.7	16.7
Monthly	A	.539 : .461	.173	24.3	60.0
	B	.908 : .092	.196	27.5	68.0

This shows that to keep within a 10 per cent error in the group 230 to 286 millimeters in length, the sampling should be as often as twice a week. In a more numerous group, such as the 178 to 230 millimeter group, the percentage error is of course much less and does not exceed 10 per cent until the sampling is as infrequent as monthly.

CONCLUSIONS.

Biological and conservational studies on a fishery that is subject to an interchange of fish populations like that of the sardine of Monterey, must be conducted with the consciousness that the specimens studied do not represent the population of the species as a whole. Fortuitous methods of collecting samples may lead to the securing of a highly selected group of fishes which may differ widely from the whole population actually present.

In the case of the Monterey sardine investigation it was found that:

1. It is probably impossible or at least impractical to secure a theoretically accurate representation of the population.
2. That to secure a representation sufficient to show the location of a distinct mode to within 10 per cent of the probable movement of that mode within one year, a sampling of twice a week is necessary.
3. In order to determine the relative importance of fairly well defined and large size-groups within 10 per cent error it is also necessary to take samples at least twice a week.

TABLE I.—Number of fish in each sample weighed and measured; and the mean sizes of the sardines in each sample and each day.

Date	Sample number	Weight, ounces		Body length, millimeters	
		Number of fish	Mean weight	Number of fish	Mean length
Nov. 14, 1919.....	1	54	3.35	21	197
	2	70	3.57	21	198
	3	82	3.67	22	199
	4	89	3.40	29	197
	5	80	3.54	22	199
	6	84	3.49	27	196
Totals.....		459	3.50	142	198
Nov. 15, 1919.....	7	81	3.57	18	199
	8	70	3.63	17	198
	9	81	3.74	20	204
	10	76	3.97	19	203
	11	71	3.66	17	197
	12	79	3.82	18	204
Totals.....		458	3.73	109	201
Nov. 17, 1919.....	15	86	3.49	21	196
	16	86	3.43	20	194
Totals.....		172	3.46	41	195
Nov 18, 1919.....	17	86	3.77	21	199
	18	75	3.76	18	203
	19	78	4.14	19	209
Totals.....		239	3.89	58	204
Nov. 19, 1919.....	20	73	4.26	18	211
	21	68	4.25	17	210
	22	19	3.74	19	202
	23	97	3.52	33	199
Totals.....		257	3.94	87	206
Nov. 20, 1919.....	24	80	4.07	36	205
	25	77	4.18	30	207
	26	80	3.94	20	205
	27	68	4.49	18	212
Totals.....		305	4.17	104	207
Nov. 21, 1919.....	28	69	4.19	18	209
	29	71	4.21	18	208
	30	23	3.83	23	203
	31	67	4.58	17	216
	32	81	4.36	20	207
Totals.....		311	4.23	96	209
Nov. 22, 1919.....	33	84	3.75	23	203
	34	81	4.07	27	202
Totals.....		165	3.91	50	202
Nov. 24, 1919.....	35	58	4.50	15	209
	36	50	5.76	12	227
	37	65	4.71	16	211
	38	82	4.04	29	205
Totals.....		255	4.75	72	213
Nov. 25, 1919.....	39	100	3.27	24	181
	40	59	3.66	20	200
	41	80	3.90	20	208
	42	76	3.68	19	198
	43	85	3.96	20	205
	44	86	3.94	21	205
Totals.....		486	3.74	124	199
Nov. 26, 1919.....	45	82	4.01	40	208
	46	85	4.12	42	206
Totals.....		167	4.07	82	207

¹Mean for day calculated by averaging the means of all samples on that day

TABLE I.—Number of fish in each sample weighed and measured; and the mean sizes of the sardines in each sample and each day—Continued.

Date	Sample number	Weight, ounces		Body length, millimeters	
		Number of fish	Mean weight	Number of fish	Mean length
Nov. 28 1919-----	47	84	4.05	43	208
	48	82	4.22	41	211
Totals-----		166	4.13	84	209
Nov. 29, 1919-----	49	83	4.41	20	210
	50	72	4.44	21	210
	51	76	4.43	20	209
	52	73	4.71	18	216
Totals-----		304	4.50	79	211
Dec. 1, 1919-----	53	92	3.77	23	203
	54	80	4.35	20	216
	55	85	3.49	21	197
	56	98	3.45	24	199
	57	87	3.78	22	200
Totals-----		442	3.77	110	203
Dec. 2, 1919-----	58	72	4.75	17	201
	59	91	3.49	22	196
	60			19	214
	61	61	5.38	21	213
	62	73	4.59	21	209
Totals-----		297	4.55	100	207
Dec. 3, 1919-----	63	100	3.31	26	194
	64	112	3.05	28	190
	65	95	3.36	23	190
	66			23	192
	67	122	2.75	122	184
Totals-----		429	3.12	222	190
Dec. 4, 1919-----	68	77	4.56	22	215
	69	76	4.41	19	216
	70	73	3.93	20	204
	71	90	3.89	23	209
Totals-----		316	4.20	84	211
Dec. 5, 1919-----	72	88	3.50	22	202
	73	82	3.99	20	206
	74	93	3.60	23	196
	75	59	4.02	21	205
Totals-----		322	3.78	86	202
Dec. 10, 1919-----	76	49	7.45	21	245
	77	67	4.78	16	218
	78	59	5.02	20	224
	79	78	4.82	20	212
	80	68	5.75	16	210
	81	50	6.66	13	236
Totals-----		371	5.75	106	224
Dec. 11, 1919-----	82	53	6.57	14	231
	83	59	5.36	14	209
	84	43	7.17	15	244
	85	45	6.71	14	241
	86	41	6.90	15	237
	87	52	6.88	18	238
Totals-----		293	6.60	90	233
Dec. 12, 1919-----	88	39	7.26	39	244
Dec. 15, 1919-----	89	60	5.52	15	220
	90	56	5.54	20	219
	91	58	4.77	19	211
	92	55	5.04	22	219
	93	76	4.46	25	208
	94	70	4.88	31	215
Totals-----		375	5.04	132	215

TABLE I.—Number of fish in each sample weighed and measured; and the mean sizes of the sardines in each sample and each day—Continued.

Date	Sample number	Weight, ounces		Body length, millimeters	
		Number of fish	Mean weight	Number of fish	Mean length
Dec. 16, 1919.....	95	56	4.64	17	216
	96	51	4.61	19	214
	97	89	3.93	27	206
	98	60	5.55	20	221
	99	72	4.61	20	216
Totals.....		328	4.67	103	215
Dec. 17, 1919.....	100			18	217
	101			22	203
	102			21	215
	103			24	219
Totals.....				85	214
Dec. 18, 1919.....	104	66	4.46	24	214
	105	43	4.30	21	207
	106	78	3.99	23	200
	107	56	4.52	17	211
Totals.....		243	4.32	85	208
Dec. 19, 1919.....	108	72	3.94	22	204
	109	63	3.86	21	205
	110	66	3.82	23	204
	111	97	3.49	24	197
	112	95	2.74	28	206
Totals.....		393	3.57	118	203
Dec. 20, 1919.....	113	47	6.40	20	236
	114	69	4.85	21	213
	115	21	6.38	21	235
	116	70	4.04	24	211
	117	43	6.05	16	234
Totals.....		250	5.54	102	226
Dec. 22, 1919.....	118	42	5.90	20	237
	119	57	5.40	20	218
Totals.....		99	5.65	40	228
Dec. 23, 1919.....	120	40	7.77	53	221
	121	53	5.36	40	222
Totals.....		93	6.56	93	221
Dec. 27, 1919.....	122	55	4.87	18	220
	123	74	4.30	25	212
	124	72	4.15	18	210
	125	26	4.04	26	207
	126	74	3.96	28	206
Totals.....		301	4.26	115	211
Dec. 29, 1919.....	128	47	6.11	17	234
	129	72	4.26	24	214
	130	52	4.65	18	216
	131	64	4.97	22	211
	132	64	4.34	34	214
Totals.....		299	4.87	115	218
Dec. 30, 1919.....	133	53	6.25	23	235
	134	61	4.57	21	213
	135	70	4.07	24	209
Totals.....		184	4.96	68	219

TABLE I.—Number of fish in each sample weighed and measured; and the mean sizes of the sardines in each sample and each day—Continued.

Date	Sample number	Weight, ounces		Body length, millimeters	
		Number of fish	Mean weight	Number of fish	Mean length
Jan. 3, 1920.....	136	41	6.39	20	231
	137	61	3.94	20	210
	138	63	4.09	22	208
	139	54	5.55	23	227
	140	91	3.53	42	203
Totals.....		310	4.70	127	216
Jan. 8, 1920.....	141	74	3.84	38	204
	142	85	3.98	85	209
Totals.....		159	3.91	123	206
Jan. 9, 1920.....	143	45	5.49	21	222
	144	61	5.13	21	223
	145	66	5.23	22	224
	146	63	5.60	24	227
	147	56	4.57	20	213
Totals.....		291	5.20	108	222
Jan. 10, 1920.....	148	45	5.62	21	233
	149			22	230
	150	63	4.44	33	214
	151	44	5.68	23	226
Totals.....		152	5.25	98	226
Jan. 12, 1920.....	152	53	4.76	26	216
	153	75	3.56	25	202
	154	66	3.80	31	203
	155	85	3.88	21	205
	156	77	3.88	33	204
Totals.....		356	3.98	136	206
Jan. 13, 1920.....	157	63	4.30	21	210
	158	53	5.43	19	214
	159	65	4.35	22	211
	160	58	4.31	20	207
	161	56	4.28	22	209
Totals.....		295	4.53	104	210
Jan. 14, 1920.....	162	52	5.02	20	221
	163	55	4.78	20	215
	164	84	3.87	21	208
	165	68	4.87	32	222
Totals.....		259	4.64	93	216
Jan. 15, 1920.....	166	68	4.54	28	217
	167	78	3.87	38	209
	168	68	4.69	22	217
	169	71	4.65	24	213
Totals.....		285	4.44	112	214
Jan. 16, 1920.....	170	54	4.37	19	209
	171	66	4.06	20	206
	172	81	3.42	21	197
	173	87	3.66	28	202
	174	80	3.64	26	202
Totals.....		368	3.83	114	203
Jan. 17, 1920.....	175	44	4.27	20	211
	176	53	4.68	22	221
	177	63	3.43	20	202
	178	62	3.74	16	205
	179	55	3.98	24	206
Totals.....		277	4.02	102	209

TABLE I.—Number of fish in each sample weighed and measured; and the mean sizes of the sardines in each sample and each day—Continued.

Date	Sample number	Weight, ounces		Body length, millimeters	
		Number of fish	Mean weight	Number of fish	Mean length
Jan. 19, 1920.....	180	63	3.54	20	200
	181	79	3.34	23	200
	182	65	3.74	21	206
	183	68	4.80	20	222
	184	68	3.56	23	203
Totals.....		334	3.80	107	206
Jan. 20, 1920.....	185	50	5.10	20	218
	186	61	4.54	20	214
	187	41	7.56	20	252
	188	69	3.67	24	205
	189	58	3.72	22	208
Totals.....		279	4.92	106	219
Jan. 21, 1920.....	190	79	3.68	22	204
	191	76	3.72	22	205
	192	40	5.57	17	223
	193	70	4.31	22	211
	194	68	4.62	23	215
Totals.....		333	4.38	106	212
Jan. 22, 1920.....	195	36	7.30	21	248
	196	37	6.81	19	243
	197	76	3.87	25	207
	198	39	7.25	20	251
	199	46	5.21	11	222
Totals.....		234	6.09	96	234
Jan. 23, 1920.....	200	39	6.59	20	232
	201	54	5.82	26	233
	202	48	6.91	48	246
Totals.....		141	6.44	94	237
Jan. 24, 1920.....	203	48	6.85	20	236
	204	38	4.60	20	211
	205	38	4.89	18	229
	206	43	6.67	18	240
	207	56	4.91	20	212
Totals.....		223	5.58	96	226
Jan. 26, 1920.....	208	39	7.33	20	251
	209	34	6.15	20	238
	210	42	7.24	19	246
	211	36	7.03	20	246
	212	39	7.61	21	251
Totals.....		190	7.07	100	246
Jan. 27, 1920.....	213	37	6.67	20	241
	214	46	6.02	23	235
	215	54	5.43	22	227
	216	61	6.03	20	233
	217	66	5.80	21	235
Totals.....		264	5.99	106	234
Jan. 28, 1920.....	218	38	6.89	20	247
	219	78	4.21	22	206
	220	45	7.06	22	247
	221	42	6.19	21	232
	222	44	6.75	22	237
Totals.....		247	6.22	107	234

TABLE I.—Number of fish in each sample weighed and measured; and the mean sizes of the sardines in each sample and each day—Continued.

Date	Sample number	Weight, ounces		Body length, millimeters	
		Number of fish	Mean weight	Number of fish	Mean length
Jan. 29, 1920.....	223	46	5.98	23	240
	224	43	7.06	21	244
	225	44	6.86	21	249
	226	43	7.33	21	252
	227	42	5.88	18	228
Totals.....		218	6.62	104	243
Jan. 30, 1920.....	228	33	7.55	21	252
	229	36	7.22	20	248
	230	38	7.10	20	251
	231	56	6.38	19	243
	232	48	6.96	22	246
Totals.....		211	7.04	102	248
Jan. 31, 1920.....	233	48	7.21	22	245
	234	34	7.44	19	248
	235	37	7.35	19	246
	236	30	7.23	20	247
	237	55	6.34	20	231
Totals.....		204	7.11	100	243
Feb. 2, 1920.....	238	43	6.70	20	239
	239	30	6.00	20	230
	240	38	6.66	21	242
	241	50	5.72	25	229
	242	51	6.76	21	242
Totals.....		212	6.37	107	236
Feb. 6, 1920.....	243	102	3.36	25	202
	244	56	5.05	19	215
	245	54	3.63	26	204
	246	74	3.49	21	200
	247	97	3.63	24	201
Totals.....		383	3.83	115	204
Feb. 7, 1920.....	248	50	6.54	22	240
	249	47	6.30	22	236
	250	50	5.60	22	228
	251	79	3.48	22	201
	252	65	5.00	26	219
Totals.....		291	5.38	114	225
Feb. 9, 1920.....	253	44	6.22	22	238
	254	54	5.85	18	228
	255			25	233
	256	34	7.44	20	252
	257	60	4.68	25	222
Totals.....		192	6.05	110	235
Feb. 10, 1920.....	258	30	7.10	23	249
	259	37	6.03	19	236
	260	45	6.44	20	242
	261	44	6.75	20	245
	262	45	6.51	17	241
Totals.....		201	6.57	99	243
Feb. 11, 1920.....	263	55	5.63	20	231
	264	51	6.14	25	232
	265	57	5.56	20	232
	266	40	6.78	19	238
	267	53	5.71	19	232
Totals.....		256	5.96	103	233

TABLE I.—Number of fish in each sample weighed and measured; and the mean sizes of the sardines in each sample and each day—Continued.

Date	Sample number	Weight, ounces		Body length, millimeters	
		Number of fish	Mean weight	Number of fish	Mean length
Feb. 12, 1920.....	268	67	4.58	20	217
	269			21	214
	270	66	3.94	20	208
	271	78	4.01	20	213
	272	75	4.28	20	216
Totals.....		286	4.20	101	214
Feb. 13, 1920.....	273	49	5.47	20	231
	274	54	5.09	23	222
	275	40	5.35	19	229
	276	53	5.81	22	231
	277	71	4.41	28	211
Total.....		267	5.23	112	225
Feb. 14, 1920.....	278	65	4.00	20	216
	279	72	4.08	22	209
	280	91	3.68	21	200
	281	76	4.18	20	210
	282	69	4.08	20	206
Totals.....		373	4.18	103	208
Feb. 16, 1920.....	283	71	4.28	20	219
	284	69	4.37	21	215
	285	83	3.82	20	206
	286	83	3.77	20	205
	287	73	4.03	20	209
	288	63	4.38	20	219
Totals.....		442	4.11	121	212
Feb. 17, 1920.....	289	81	3.47	20	203
	290	77	3.60	20	206
	291	71	3.78	20	206
	292	80	3.41	20	203
	293	87	3.58	20	209
	294	86	3.44	22	203
Totals.....		482	3.55	122	205
Feb. 18, 1920.....	295	91	3.82	20	203
	296	72	3.50	20	205
	297	67	3.33	20	200
	298	89	3.66	20	206
	299	65	3.97	20	201
Totals.....		384	3.66	100	203
Feb. 19, 1920.....	300	87	3.36	43	201
	301	68	4.18	34	213
Totals.....		155	3.77	77	207
Feb. 27, 1920.....	302	41	7.56	17	254
	303			19	253
	304	31	7.68	19	255
	305	46	8.02	17	255
Totals.....		118	7.75	72	254
Feb. 28, 1920.....	306	45	6.73	22	242
	307	42	8.43	21	250
	308	42	7.18	20	253
	309	48	5.85	23	230
	310	33	6.97	33	244
Totals.....		210	7.03	119	244

TABLE 1.—Number of fish in each sample weighed and measured; and the mean sizes of the sardines in each sample and each day—Continued.

Date	Sample number	Weight, ounces		Body length, millimeters	
		Number of fish	Mean weight	Number of fish	Mean length
Mar. 1, 1920.....	311	47	6.68	23	246
	312	52	7.33	26	250
	313	43	6.53	18	245
	314	51	6.78	25	239
	315	31	6.18	24	241
Totals.....		224	6.70	116	244
Mar. 2, 1920.....	316	59	4.17	24	210
	317	71	4.67	21	221
	318	74	4.47	20	217
	319	84	4.14	21	209
	320	50	4.88	20	225
Totals.....		338	4.47	106	216
Mar. 3, 1920.....	321	52	4.69	22	223
Mar. 8, 1920.....	322	71	4.34	23	219
	323	63	4.30	20	211
	324	58	4.12	20	208
	325	81	3.98	19	204
Totals.....		273	4.18	82	210
Mar. 9, 1920.....	326	60	4.05	20	209
	327	77	3.79	20	208
	328	64	4.50	21	217
	329	33	5.15	21	230
	330	55	5.12	20	219
Totals.....		289	4.52	102	217
Mar. 11, 1920.....	331	79	3.92	20	207
	332	94	3.59	23	204
	333	72	3.93	18	214
	334	68	3.32	22	199
	335	50	3.56	25	203
Totals.....		363	3.66	108	205
Mar. 12, 1920.....	336	71	3.58	23	202
	337	73	3.51	24	204
	338	49	3.39	22	197
	339	86	3.67	21	206
Totals.....		279	3.54	90	202
Mar. 13, 1920.....	340	75	3.43	24	198
	341	103	3.40	20	199
	342	69	3.45	17	201
	343	90	3.23	22	199
	344	72	3.56	21	198
Totals.....		409	3.41	104	199
Grand totals.....		20,927		7,668	

TABLE II.—The numbers of sardines in each sample above and below 178 millimeters body-length respectively and the totals of each for day.

Date	Samples										Totals for day	
	Below 178 mm.	Above 178 mm.	Below 178 mm.	Above 178 mm.	Below 178 mm.	Above 178 mm.	Below 178 mm.	Above 178 mm.	Below 178 mm.	Above 178 mm.	Total	Total
Nov. 14, 1919.	1	20	--	21	--	21	--	21	--	19	123	124
Nov. 15, 1919.	--	17	--	17	--	17	--	17	--	16	101	102
Nov. 17, 1919.	2	19	2	18	--	--	--	--	--	--	37	41
Nov. 18, 1919.	--	20	--	18	--	19	--	--	--	--	57	57
Nov. 19, 1919.	--	18	--	17	--	19	--	18	--	--	72	72
Nov. 20, 1919.	--	20	1	19	--	20	--	18	--	--	77	78
Nov. 21, 1919.	--	18	--	18	1	19	--	17	--	20	92	93
Nov. 22, 1919.	--	23	--	23	--	--	--	--	--	--	46	46
Nov. 24, 1919.	1	14	--	12	--	16	--	15	--	--	57	58
Nov. 25, 1919.	4	16	--	20	--	20	1	18	--	20	115	120
Nov. 26, 1919.	1	39	4	36	--	--	--	--	--	--	75	80
Nov. 28, 1919.	2	39	1	40	--	--	--	--	--	--	79	82
Nov. 29, 1919.	--	20	--	20	--	19	--	18	--	--	77	77
Dec. 1, 1919.	--	20	--	20	--	20	--	2	18	--	98	100
Dec. 2, 1919.	4	13	1	18	--	18	3	15	1	17	81	90
Dec. 3, 1919.	--	20	3	17	4	16	2	18	4	16	87	100
Dec. 4, 1919.	--	19	--	19	1	18	--	19	--	--	75	76
Dec. 5, 1919.	--	20	--	20	2	18	--	20	--	--	78	80
Dec. 10, 1919.	--	14	--	14	--	14	--	15	1	13	83	84
Dec. 11, 1919.	1	13	1	13	--	14	--	14	--	14	82	84
Dec. 12, 1919.	--	39	--	--	--	--	--	--	--	--	39	39
Dec. 15, 1919.	--	15	--	15	--	15	--	15	1	14	89	90
Dec. 16, 1919.	--	17	--	18	--	18	--	18	1	18	89	90
Dec. 17, 1919.	--	18	1	18	--	18	--	18	--	--	71	72
Dec. 18, 1919.	--	18	--	18	1	18	--	17	--	--	71	72
Dec. 19, 1919.	--	20	--	20	--	20	2	18	--	20	98	100
Dec. 20, 1919.	--	16	--	16	--	16	--	16	--	16	80	80
Dec. 22, 1919.	--	20	2	18	--	--	--	--	--	--	38	40
Dec. 23, 1919.	--	36	--	36	--	--	--	--	--	--	72	72
Dec. 27, 1919.	--	18	--	18	--	18	--	18	--	18	90	90
Dec. 29, 1919.	--	17	--	17	--	17	--	17	--	17	85	85
Dec. 30, 1919.	--	22	--	22	--	22	--	--	--	--	66	66
Jan. 3, 1920.	--	20	--	20	2	18	--	20	1	19	87	100
Jan. 8, 1920.	--	38	--	38	--	--	--	--	--	--	76	76
Jan. 9, 1920.	--	20	--	20	--	20	--	20	1	19	99	100
Jan. 10, 1920.	--	21	--	21	--	21	1	20	--	--	83	84
Jan. 12, 1920.	--	20	1	19	--	20	--	20	1	19	98	100
Jan. 13, 1920.	--	21	--	19	--	20	--	20	--	20	100	100
Jan. 14, 1920.	--	20	--	20	--	20	--	20	--	--	80	80
Jan. 15, 1920.	--	22	--	22	--	22	--	22	--	--	88	88
Jan. 16, 1920.	--	19	--	20	--	20	--	21	--	20	100	100
Jan. 17, 1920.	1	15	--	16	--	16	--	16	--	16	79	80
Jan. 19, 1920.	--	20	1	19	--	20	--	20	1	19	98	100
Jan. 20, 1920.	--	20	--	20	--	20	--	20	1	19	99	100
Jan. 21, 1920.	--	20	--	21	--	17	--	21	--	21	100	100
Jan. 22, 1920.	--	21	--	19	--	20	--	20	--	11	91	91
Jan. 23, 1920.	--	20	--	20	--	20	--	--	--	--	60	60
Jan. 24, 1920.	--	20	--	20	--	18	--	18	--	20	96	96
Jan. 26, 1920.	--	20	--	20	--	19	--	21	--	20	100	100
Jan. 27, 1920.	--	20	--	20	1	19	--	20	--	20	99	100
Jan. 28, 1920.	--	20	--	20	--	21	--	21	--	18	99	100
Jan. 29, 1920.	--	20	--	20	--	20	--	20	--	21	100	100
Jan. 30, 1920.	--	21	--	19	--	20	--	19	--	--	100	100
Jan. 31, 1920.	--	22	--	19	--	19	--	20	--	20	100	100

TABLE III.—Length frequency distribution of all samples of "pound-oval" sardines taken November 14, 1919 to March 13, 1920.

(The frequencies are shown as untreated, "weighted" to equivalent of 100 fish per day of all sizes, and "weighted" to equivalent of 100 fish above 178 millimeters per day, and smoothed as presented in the text figures.)

I	II	III	IV	V	VI	VII
Body length, millimeters	Frequency	Frequency smoothed by 3's	Weighted frequency	Weighted frequency smoothed by 3's	Weighted frequency of fish longer than 178 mm. smoothed by 3's	Column VI reduced to percentage frequency
111.		.3		.3		
112.	1	.3	.8	.3		
113.		.3		.3		
114.						
115.		.3		.3		
116.	1	.7	.8	.5		
117.	1	.7	.8	.5		
118.		.3		.3		
119.						
120.						
121.		.7		1.2		
122.	2	.7	3.6	1.2		
123.		.7		1.2		
124.						
125.		.3		.3		
126.	1	.3	.8	.3		
127.		.3		.3		
128.						
129.						
130.						
131.		.7		.7		
132.	2	1.4	2.2	1.3		
133.	2	1.7	1.8	1.7		
134.	1	1.4	1.1	1.3		
135.	1	1.0	1.0	1.5		
136.	1	.7	2.4	1.1		
137.		1.0		2.0		
138.	2	1.0	3.6	1.7		
139.	1	1.4	1.4	2.0		
140.	1	2.0	1.0	2.7		
141.	4	2.3	5.8	3.0		
142.	2	2.3	2.1	3.0		
143.	1	1.0	1.0	1.0		
144.		1.0		1.0		
145.	2	1.7	2.1	2.5		
146.	3	3.0	5.4	3.8		
147.	4	2.7	4.0	3.6		
148.	1	2.7	1.3	2.9		
149.	3	1.7	3.4	1.9		
150.	1	1.4	1.0	1.5		
151.		1.0		1.6		
152.	2	1.0	3.7	1.6		
153.	1	2.0	1.0	2.6		
154.	3	2.7	3.2	2.8		
155.	4	2.7	4.1	2.8		
156.	1	3.0	1.2	3.2		
157.	4	2.3	4.2	2.5		
158.	2	2.3	2.2	2.5		
159.	1	1.0	1.0	1.1		
160.		.7		.7		
161.	1	.7	1.1	.8		
162.	1	1.3	1.2	1.6		
163.	2	1.0	2.5	1.2		
164.		1.0		1.4		
165.	1	1.0	1.7	1.2		
166.	2	1.0	2.0	1.2		
167.		.7		.7		
168.		.7		.8		
169.	2	1.0	2.4	1.1		
170.	1	2.0	8	2.1		
171.	3	1.7	3.0	1.3		
172.		2.7		3.2		
173.	5	1.7	6.7	2.2		
174.		2.7		3.3		
175.	3	1.0	3.1	1.0		
176.						

TABLE III.—Length frequency distribution of all samples of "pound-oval" sardines taken November 14, 1919 to March 13, 1920.—Continued.

(The frequencies are shown as untreated, "weighted" to equivalent of 100 fish per day of all sizes, and "weighted" to equivalent of 100 fish above 178 millimeters per day, and smoothed as presented in the text figures.)

I	II	III	IV	V	VI	VII
Body length, millimeters	Frequency	Frequency smoothed by 3's	Weighted frequency	Weighted frequency smoothed by 3's	Weighted frequency of fish longer than 178 mm. smoothed by 3's	Column VI reduced to percentage frequency
177		1.0		1.0		
178		.7		.9		
179	2	1.3	2.8	1.8	1.8	.02
180	2	3.0	2.6	2.7	3.8	.05
181	5	4.3	2.8	3.9	5.0	.06
182	6	7.7	6.4	7.6	8.8	.11
183	12	8.7	13.6	10.6	10.1	.13
184	8	11.3	11.8	13.3	12.8	.17
185	14	14.0	14.4	16.1	15.8	.21
186	20	18.7	22.2	21.3	20.8	.27
187	22	28.3	27.4	28.7	28.8	.37
188	33	33.3	36.6	38.3	37.7	.49
189	45	44.3	51.0	51.9	51.1	.66
190	55	57.0	68.1	66.3	64.5	.84
191	71	73.0	79.8	82.5	81.7	1.06
192	93	97.3	99.5	107.5	106.2	1.38
193	128	120.0	143.1	131.9	131.1	1.70
194	139	140.0	153.2	155.0	152.9	1.98
195	153	154.7	168.8	171.9	169.8	2.20
196	172	163.7	193.8	187.8	186.8	2.41
197	184	178.3	200.8	195.9	195.6	2.54
198	179	182.7	193.0	203.6	204.0	2.65
199	185	185.0	217.0	207.2	205.9	2.67
200	191	177.7	211.7	200.7	201.0	2.61
201	157	185.0	173.5	204.4	206.6	2.68
202	207	181.3	228.0	202.2	205.8	2.68
203	180	192.0	205.1	212.9	216.8	2.82
204	189	183.0	205.7	206.2	210.4	2.73
205	180	180.0	207.8	201.3	207.9	2.70
206	171	159.7	191.4	190.3	186.0	2.41
207	128	143.7	141.7	168.8	169.3	2.20
208	135	123.7	163.4	142.9	145.4	1.89
209	108	122.3	123.5	141.6	146.6	1.90
210	124	111.0	137.8	124.9	131.2	1.71
211	101	109.0	113.5	122.2	126.6	1.64
212	102	100.0	115.3	113.0	115.4	1.50
213	97	97.7	110.3	112.3	115.3	1.50
214	94	96.0	111.2	111.9	116.7	1.51
215	97	91.3	114.2	108.3	112.2	1.46
216	83	81.7	99.5	95.9	99.2	1.29
217	65	84.7	74.1	101.0	106.0	1.38
218	106	78.7	129.4	94.5	98.9	1.28
219	65	78.0	80.1	94.4	99.1	1.29
220	63	65.7	73.9	79.2	82.0	1.06
221	69	65.7	83.6	76.6	81.1	1.05
222	65	64.3	72.2	76.2	80.9	1.05
223	59	63.3	72.8	74.3	77.6	1.01
224	66	60.0	78.0	71.0	72.6	.94
225	55	57.0	62.1	66.3	66.1	.86
226	50	53.7	58.7	62.5	62.4	.81
227	56	53.0	66.8	62.9	62.9	.82
228	53	53.7	63.2	63.0	63.5	.85
229	49	52.3	59.1	61.6	62.1	.81
230	55	49.3	62.5	57.2	57.6	.75
231	44	49.0	49.9	55.8	56.1	.73
232	48	48.0	55.0	57.5	57.8	.75
233	52	55.7	67.6	67.6	67.7	.88
234	67	58.3	80.2	71.0	71.4	.93
235	56	57.0	65.2	68.0	68.3	.89
236	48	52.0	58.5	62.3	62.8	.82
237	52	49.7	63.1	59.0	59.6	.77
238	49	52.3	55.3	61.1	61.7	.80
239	56	52.0	64.8	60.2	60.8	.79
240	51	57.3	60.4	68.9	69.4	.90
241	65	59.3	81.4	72.5	72.7	.94
242	62	66.7	78.8	80.6	80.9	1.05

TABLE III.—Length frequency distribution of all samples of "pound-oval" sardines taken November 14, 1919 to March 13, 1920.—Continued.

(The frequencies are shown as untreated, "weighted" to equivalent of 100 fish per day of all sizes, and "weighted" to equivalent of 100 fish above 178 millimeters per day, and smoothed as presented in the text figures.)

I	II	III	IV	V	VI	VII
Body length, millimeters	Frequency	Frequency smoothed by 3's	Weighted frequency	Weighted frequency smoothed by 3's	Weighted frequency of fish longer than 178 mm. smoothed by 3's	Column VI reduced to percentage frequency
243	73	62.7	84.6	74.0	74.3	.96
244	53	62.7	61.7	73.1	73.3	.95
245	62	57.7	73.1	68.9	69.1	.90
246	58	60.7	72.0	71.9	71.9	.93
247	62	61.7	70.5	70.6	70.9	.92
248	65	62.3	69.4	69.1	69.6	.90
249	60	65.0	67.3	70.6	71.2	.92
250	70	61.7	75.2	68.3	68.9	.89
251	55	61.3	62.3	68.2	68.7	.89
252	59	53.0	67.2	59.5	59.9	.78
253	45	54.0	49.0	60.8	61.1	.79
254	58	51.0	66.1	56.6	56.7	.74
255	50	48.3	54.6	53.7	53.8	.70
256	37	45.0	40.3	48.5	48.7	.63
257	48	42.7	50.7	45.8	45.9	.60
258	43	45.0	46.3	48.2	48.3	.63
259	44	44.0	47.6	49.6	49.9	.65
260	45	42.7	54.9	47.8	48.1	.62
261	39	36.0	41.0	40.5	40.7	.53
262	24	27.0	25.6	28.4	28.5	.37
263	18	24.3	18.7	26.8	26.9	.34
264	31	25.0	36.1	27.9	28.1	.36
265	26	23.0	28.9	26.1	26.2	.34
266	12	21.0	13.2	22.9	23.1	.30
267	25	19.0	26.7	20.4	20.5	.27
268	20	18.7	21.3	20.0	20.1	.26
269	11	14.7	12.0	15.4	15.4	.20
270	13	11.7	12.8	12.5	12.5	.16
271	13	11.7	12.8	12.7	12.7	.16
272	11	11.0	12.6	12.6	12.6	.16
273	11	9.0	12.3	10.1	10.1	.13
274	5	7.7	5.3	8.2	8.2	.10
275	7	5.7	7.0	5.8	5.8	.08
276	5	5.7	5.0	5.7	5.8	.08
277	5	4.0	5.2	4.1	4.1	.05
278	2	4.3	2.0	4.8	4.8	.06
279	6	3.7	7.1	4.2	4.2	.05
280	3	3.3	3.4	3.8	3.8	.05
281	1	1.7	1.0	1.9	1.9	.02
282	1	.7	1.4	.8	.8	.01
283		.3		.5	.5	.01
284						
285		.3		.8	.9	.01
286	1	.3	2.5	.8	.9	.01
287		.3		.8	.9	.01
Totals	6,750	6,748.6	7,698.2	7,698.1	7,699.7	99.91

TABLE IV.—Comparison of the dates, and number of fish taken in the Norwegian spring herring investigation and the California sardine investigation.

Herring investigation		Sardine investigation	
Date	Number of fish	Date	Number of fish
Jan. 31	228	Dec. 17	82
Feb. 15	280	Jan. 3	124
Mar. 1	379	Jan. 15	112
Mar. 8	390	Jan. 22	107
Mar. 10	408	Jan. 24	96
Mar. 12	417	Jan. 26	100
Mar. 13	418	Jan. 27	105
Mar. 15	909	Jan. 29	104
Mar. 17	432	Jan. 31	100
Mar. 29	465	Feb. 12	101
Total	4,326	Total	1,031

Samples on alternate days		Samples twice a week*				Samples weekly*				Samples twice a month*						Samples monthly**	
(A)	(B)	(A)	(B)	(C)		(A)	(B)	(C)	(D)	(E)	(F)	(A)	(B)				
1919 Nov. 14	1919 Nov. 15	1919 Nov. 17	1919 Nov. 18	1919 Nov. 14	1919 Nov. 15	1919 Nov. 17	1919 Nov. 18	1919 Nov. 14	1919 Nov. 15	1919 Nov. 16	1919 Nov. 17	1919 Nov. 18	1919 Nov. 19				
1919 Nov. 17	1919 Nov. 18	1919 Nov. 20	1919 Nov. 21	1919 Nov. 18	1919 Nov. 19	1919 Nov. 21	1919 Nov. 22	1919 Nov. 19	1919 Nov. 20	1919 Nov. 21	1919 Nov. 22	1919 Nov. 23	1919 Nov. 24				
1919 Nov. 20	1919 Nov. 21	1919 Nov. 23	1919 Nov. 24	1919 Nov. 21	1919 Nov. 22	1919 Nov. 24	1919 Nov. 25	1919 Nov. 22	1919 Nov. 23	1919 Nov. 24	1919 Nov. 25	1919 Nov. 26	1919 Nov. 27				
1919 Nov. 23	1919 Nov. 24	1919 Nov. 26	1919 Nov. 27	1919 Nov. 24	1919 Nov. 25	1919 Nov. 27	1919 Nov. 28	1919 Nov. 25	1919 Nov. 26	1919 Nov. 27	1919 Nov. 28	1919 Nov. 29	1919 Nov. 30				
1919 Nov. 26	1919 Nov. 27	1919 Nov. 29	1919 Nov. 30	1919 Nov. 27	1919 Nov. 28	1919 Nov. 30	1919 Dec. 1	1919 Nov. 28	1919 Nov. 29	1919 Nov. 30	1919 Dec. 1	1919 Dec. 2	1919 Dec. 3				
1919 Dec. 1	1919 Dec. 2	1919 Dec. 4	1919 Dec. 5	1919 Dec. 2	1919 Dec. 3	1919 Dec. 5	1919 Dec. 6	1919 Dec. 3	1919 Dec. 4	1919 Dec. 5	1919 Dec. 6	1919 Dec. 7	1919 Dec. 8				
1919 Dec. 4	1919 Dec. 5	1919 Dec. 7	1919 Dec. 8	1919 Dec. 7	1919 Dec. 8	1919 Dec. 9	1919 Dec. 10	1919 Dec. 9	1919 Dec. 10	1919 Dec. 11	1919 Dec. 12	1919 Dec. 13	1919 Dec. 14				
1919 Dec. 7	1919 Dec. 8	1919 Dec. 10	1919 Dec. 11	1919 Dec. 10	1919 Dec. 11	1919 Dec. 12	1919 Dec. 13	1919 Dec. 12	1919 Dec. 13	1919 Dec. 14	1919 Dec. 15	1919 Dec. 16	1919 Dec. 17				
1919 Dec. 10	1919 Dec. 11	1919 Dec. 13	1919 Dec. 14	1919 Dec. 13	1919 Dec. 14	1919 Dec. 15	1919 Dec. 16	1919 Dec. 15	1919 Dec. 16	1919 Dec. 17	1919 Dec. 18	1919 Dec. 19	1919 Dec. 20				
1919 Dec. 13	1919 Dec. 14	1919 Dec. 16	1919 Dec. 17	1919 Dec. 16	1919 Dec. 17	1919 Dec. 18	1919 Dec. 19	1919 Dec. 18	1919 Dec. 19	1919 Dec. 20	1919 Dec. 21	1919 Dec. 22	1919 Dec. 23				
1919 Dec. 16	1919 Dec. 17	1919 Dec. 19	1919 Dec. 20	1919 Dec. 19	1919 Dec. 20	1919 Dec. 21	1919 Dec. 22	1919 Dec. 21	1919 Dec. 22	1919 Dec. 23	1919 Dec. 24	1919 Dec. 25	1919 Dec. 26				
1919 Dec. 19	1919 Dec. 20	1919 Dec. 22	1919 Dec. 23	1919 Dec. 22	1919 Dec. 23	1919 Dec. 24	1919 Dec. 25	1919 Dec. 24	1919 Dec. 25	1919 Dec. 26	1919 Dec. 27	1919 Dec. 28	1919 Dec. 29				
1919 Dec. 22	1919 Dec. 23	1919 Dec. 25	1919 Dec. 26	1919 Dec. 25	1919 Dec. 26	1919 Dec. 27	1919 Dec. 28	1919 Dec. 27	1919 Dec. 28	1919 Dec. 29	1919 Dec. 30	1919 Jan. 1	1919 Jan. 2				
1919 Dec. 25	1919 Dec. 26	1919 Dec. 28	1919 Dec. 29	1919 Dec. 28	1919 Dec. 29	1919 Dec. 30	1919 Jan. 1	1919 Dec. 29	1919 Dec. 30	1919 Jan. 1	1919 Jan. 2	1919 Jan. 3	1919 Jan. 4				
1919 Dec. 28	1919 Dec. 29	1919 Dec. 31	1919 Jan. 1	1919 Jan. 1	1919 Jan. 2	1919 Jan. 3	1919 Jan. 4	1919 Jan. 3	1919 Jan. 4	1919 Jan. 5	1919 Jan. 6	1919 Jan. 7	1919 Jan. 8				
1919 Dec. 31	1919 Jan.																

*When there were no fish taken on the regular day, the nearest subsequent day was used.

**Samples were taken on groups of days in order to secure enough fish for comparison.

TABLE VI.—Length frequencies resulting from sampling on alternate days.

Body lengths, milli- meters	Trial A			Trial B		
	Actual	Weighted	Smoothed, per cent	Actual	Weighted	Smoothed, per cent
179.....	1	1.02	.02	1	1.75	.03
180.....	1	1.20	.04	1	1.41	.05
181.....	3	2.84	.07	2	3.04	.06
182.....	4	4.45	.16	2	2.15	.07
183.....	10	11.30	.17	2	2.62	.09
184.....	4	4.50	.22	4	5.17	.11
185.....	10	10.35	.24	4	4.45	.17
186.....	12	12.99	.32	8	9.85	.22
187.....	12	13.99	.39	10	10.88	.36
188.....	16	18.44	.54	17	20.18	.43
189.....	30	31.14	.71	15	18.36	.62
190.....	28	32.99	.91	27	32.27	.77
191.....	40	41.94	1.09	31	36.86	1.03
192.....	48	52.39	1.51	45	48.61	1.24
193.....	76	82.72	1.82	52	56.21	1.58
194.....	71	77.67	2.11	68	75.81	1.86
195.....	80	86.12	2.10	73	80.07	2.32
196.....	77	82.00	2.36	95	107.83	2.50
197.....	99	107.79	2.38	85	96.47	2.71
198.....	84	88.04	2.59	95	104.75	2.71
199.....	93	107.19	2.51	92	107.79	2.84
200.....	90	98.93	2.42	101	111.02	2.81
201.....	68	76.66	2.37	89	101.29	3.00
202.....	92	101.50	2.37	115	130.16	2.98
203.....	83	99.35	2.60	97	108.53	3.04
204.....	91	102.75	2.76	98	108.02	2.70
205.....	99	121.42	2.74	81	91.01	2.66
206.....	80	96.46	2.47	91	103.93	2.36
207.....	64	71.33	2.12	64	73.90	2.28
208.....	65	79.97	1.83	70	82.29	1.95
209.....	50	62.50	1.81	58	66.27	2.00
210.....	56	68.87	1.56	68	79.83	1.85
211.....	44	50.82	1.59	57	65.14	1.70
212.....	60	65.76	1.50	42	49.34	1.50
213.....	49	58.50	1.52	48	56.73	1.47
214.....	42	53.73	1.52	52	61.81	1.52
215.....	51	65.09	1.38	46	54.43	1.54
216.....	34	42.45	1.18	49	59.03	1.40
217.....	28	30.87	1.17	37	45.68	1.59
218.....	42	63.48	1.21	64	76.43	1.36
219.....	37	47.67	1.32	28	32.51	1.25
220.....	34	43.28	1.19	29	34.05	.93
221.....	36	48.69	1.10	33	39.95	1.00
222.....	30	37.24	1.09	35	40.06	1.01
223.....	28	41.12	1.06	31	35.64	.95
224.....	36	45.55	.92	30	33.14	.97
225.....	18	20.63	.81	37	41.67	.91
226.....	25	28.87	.68	25	28.41	.96
227.....	22	28.39	.73	34	39.15	.91
228.....	22	27.87	.70	31	36.14	.96
229.....	20	25.09	.71	29	33.88	.91
230.....	24	29.47	.69	31	35.76	.80
231.....	23	26.46	.73	21	24.01	.73
232.....	26	29.08	.76	22	25.63	.75
233.....	22	32.73	.96	30	35.42	.80
234.....	41	50.44	1.02	26	29.69	.83
235.....	30	36.23	1.00	26	29.66	.77
236.....	23	30.31	.88	25	28.73	.75
237.....	27	36.19	.78	25	27.37	.77
238.....	20	24.41	.82	29	31.83	.79
239.....	28	34.94	.78	28	30.41	.80
240.....	25	31.27	.94	26	29.50	.86
241.....	30	43.32	.98	35	38.66	.91
242.....	32	40.33	1.11	30	35.10	.99
243.....	39	46.43	1.02	34	38.89	.97
244.....	26	32.78	1.04	27	29.28	.86
245.....	34	42.04	.94	28	30.58	.91
246.....	23	34.62	.96	35	37.88	.95
247.....	29	35.23	.90	33	35.36	.87
248.....	33	35.08	.94	32	34.63	.85
249.....	33	39.49	1.00	27	28.98	.75
250.....	38	42.24	1.04	32	33.23	.76
251.....	33	39.75	1.02	22	22.80	.65
252.....	31	37.57	.91	28	30.56	.74
253.....	26	28.81	.85	19	20.24	.64
254.....	26	32.98	.83	32	33.34	

TABLE VI.—Length frequencies resulting from sampling on alternate days.—Continued.

Body lengths, milli- meters	Trial A			Trial B		
	Actual	Weighted	Smoothed, per cent	Actual	Weighted	Smoothed, per cent
255	31	35.00	.75	19	19.76	.65
256	17	19.38	.67	20	20.91	.59
257	23	24.19	.56	25	26.69	.64
258	19	21.42	.59	24	24.96	.67
259	21	23.15	.66	23	24.57	.64
260	23	31.97	.67	22	23.50	.58
261	22	22.66	.60	17	18.43	.45
262	15	15.91	.42	9	9.74	.32
263	10	10.22	.39	8	8.58	.31
264	15	19.38	.42	16	16.85	.31
265	16	19.02	.38	10	10.21	.29
266	6	6.62	.31	6	6.59	.29
267	10	10.64	.23	15	16.11	.30
268	9	9.92	.25	11	11.44	.27
269	8	9.03	.22	3	3.00	.18
270	7	6.68	.17	6	6.13	.15
271	4	4.67	.17	7	8.13	.16
272	7	8.42	.17	4	4.21	.15
273	6	6.81	.16	5	5.53	.10
274	3	3.19	.11	2	2.14	.10
275	3	3.01	.09	4	4.06	.06
276	4	4.00	.08	1	1.01	.07
277	2	2.00	.07	3	3.16	.04
278	2	2.00	.08			.05
279	4	5.06	.09	2	2.01	.02
280	3	3.40	.07			.03
281			.04	1	1.00	.01
282	1	1.39	.01			.01
283			.01			
284						
285			.02			
286	1	2.63	.02			
Totals	3,309	3,899.88	100.07	3,364	3,800.23	100.00

TABLE VII — Length frequencies resulting from sampling twice a week.

Body lengths, milli- meters	Trial A			Trial B			Trial C		
	Actual	Weighted	Smoothed, per cent	Actual	Weighted	Smoothed, per cent	Actual	Weighted	Smoothed per cent
179	1	1.02	.04	1	1.75	.03			.01
180	2	2.61	.06	1	1.20	.06	1	1.20	.05
181	2	2.03	.07	3	2.69	.08	2	3.18	.08
182	2	2.13	.09	3	3.39	.14	3	3.30	.14
183	4	4.25	.08	6	7.30	.15	6	6.79	.17
184	1	1.30	.10	3	3.43	.18	4	4.94	.21
185	3	3.70	.12	7	6.89	.21	7	7.55	.21
186	5	6.47	.17	9	10.14	.25	7	7.50	.30
187	4	6.04	.24	7	6.79	.37	12	13.16	.43
188	9	10.21	.38	16	18.95	.48	16	19.24	.54
189	17	19.12	.53	20	20.82	.71	15	18.11	.76
190	17	19.84	.68	25	28.05	.89	27	33.33	.98
191	22	24.19	.80	35	36.26	1.16	32	39.47	1.37
192	27	30.21	1.12	44	46.86	1.55	50	54.89	1.69
193	46	50.12	1.48	64	65.47	1.81	53	62.47	1.99
194	49	57.41	1.73	60	61.63	2.16	59	68.10	2.06
195	49	53.53	2.05	75	80.18	2.18	54	60.83	2.28
196	70	79.64	2.18	64	67.51	2.39	74	83.17	2.48
197	62	70.03	2.35	78	82.11	2.49	75	86.69	2.68
198	63	68.61	2.46	85	89.43	2.64	72	79.15	2.78
199	75	90.14	2.52	74	81.51	2.68	80	92.63	2.73
200	66	76.05	2.55	81	86.43	2.54	75	81.76	2.66
201	60	71.22	2.49	69	76.45	2.78	64	72.64	2.63
202	73	84.03	2.47	98	104.45	2.70	78	90.08	2.73
203	64	74.09	2.58	74	78.54	2.86	74	91.35	2.84
204	71	82.66	2.55	85	91.67	2.77	75	82.48	2.85
205	67	80.22	2.65	87	95.28	2.80	74	91.27	2.80
206	71	84.05	2.53	72	82.28	2.54	75	86.71	2.54
207	61	70.83	2.45	62	66.52	2.16	50	58.11	2.33
208	58	72.88	2.16	52	58.77	1.87	60	72.23	1.93
209	46	57.32	2.09	49	54.56	1.94	42	49.34	1.80
210	49	64.48	1.85	65	73.08	1.85	39	46.29	1.60
211	42	49.03	1.84	45	49.94	1.73	46	53.21	1.54
212	51	57.33	1.68	39	43.01	1.54	37	43.55	1.52
213	40	50.15	1.68	49	55.24	1.48	38	45.02	1.40
214	38	49.00	1.59	38	43.48	1.47	35	42.54	1.56
215	41	49.15	1.49	38	42.39	1.36	43	57.20	1.51
216	34	40.22	1.37	40	44.92	1.28	30	40.39	1.35
217	31	36.29	1.46	30	35.13	1.42	24	27.78	1.31
218	44	58.86	1.44	48	55.75	1.32	38	53.93	1.19
219	30	39.15	1.39	31	35.41	1.33	25	29.14	1.28
220	25	31.66	1.20	31	36.58	1.07	31	36.45	1.05
221	31	40.85	1.06	26	30.26	1.08	24	31.83	1.11
222	21	26.40	1.02	32	36.98	.96	30	35.19	1.07
223	20	28.01	.89	23	25.33	.97	24	32.47	1.13
224	24	28.43	.88	27	30.37	.92	30	37.46	1.05
225	22	24.96	.84	29	32.52	.87	24	27.75	.92
226	21	24.90	.89	19	21.08	.81	18	20.04	.83
227	29	32.67	.87	21	23.86	.87	23	29.52	.65
228	20	23.80	.79	32	39.00	.93	10	11.22	.74
229	16	17.42	.81	22	26.16	.89	22	28.56	.69
230	28	34.26	.80	19	20.63	.73	22	24.30	.77
231	20	22.58	.83	20	23.42	.73	17	18.99	.62
232	18	19.98	.73	22	26.09	.82	13	14.22	.61
233	20	25.04	.79	22	29.20	.87	18	23.53	.84
234	24	28.31	.81	22	27.84	.90	35	40.30	.94
235	19	22.05	.74	24	29.51	.92	21	23.63	.92
236	16	18.16	.68	24	30.87	.85	19	21.31	.75
237	19	23.35	.70	18	21.49	.76	20	25.17	.71
238	19	23.56	.81	18	20.66	.68	18	19.46	.70
239	25	28.59	.86	18	23.43	.65	19	20.25	.66
240	24	28.22	.97	15	18.64	.75	18	21.53	.77
241	27	33.09	1.04	23	29.90	.81	25	30.22	.83
242	29	35.00	1.10	23	29.61	1.01	22	25.75	.89
243	31	35.03	.94	31	37.84	1.02	24	26.75	.74
244	16	17.48	.87	24	30.48	.95	15	16.32	.83
245	24	28.04	.68	17	22.70	.93	31	34.40	.83
246	16	17.79	.88	27	35.67	.84	21	26.66	.95
247	33	36.22	.94	19	22.69	.86	22	27.62	.87
248	30	33.19	1.03	22	24.04	.80	25	26.29	.97
249	24	26.57	1.01	24	30.07	.87	31	34.33	.91
250	31	33.79	.94	25	29.69	.89	21	23.68	.81
251	23	26.85	1.06	25	30.38	.82	16	17.85	.63
252	32	38.33	.94	21	24.99	.76	15	16.77	.68
253	20	21.82	.89	20	22.98	.73	27	28.61	.75
254	23	25.05	.83	18	24.73	.73			

TABLE VII.—Length frequencies resulting from sampling twice a week.—Continued.

Body lengths, milli- meters	Trial A			Trial B			Trial C		
	Actual	Weighted	Smoothed, per cent	Actual	Weighted	Smoothed, per cent	Actual	Weighted	Smoothed, per cent
255.....	27	30.44	.74	20	23.24	.65	21	24.06	.76
256.....	12	13.12	.73	12	14.61	.60	17	18.12	.64
257.....	22	24.41	.62	18	19.42	.50	16	17.07	.66
258.....	19	20.45	.71	12	14.31	.56	24	26.64	.64
259.....	20	21.33	.65	18	19.85	.57	14	16.18	.75
260.....	17	19.04	.65	15	20.66	.58	21	26.75	.59
261.....	19	20.08	.53	14	15.57	.48	11	12.00	.50
262.....	10	10.42	.44	9	10.15	.32	7	7.48	.26
263.....	10	10.66	.39	5	5.34	.29	5	5.20	.31
264.....	12	15.24	.47	10	12.87	.35	15	16.46	.31
265.....	15	18.02	.45	14	15.58	.36	6	7.37	.30
266.....	8	8.82	.43	5	5.90	.29	3	4.05	.23
267.....	12	13.32	.34	6	6.53	.23	9	9.68	.23
268.....	9	9.36	.33	8	9.36	.18	7	7.48	.22
269.....	8	8.36	.25	1	1.67	.17	3	3.12	.13
270.....	6	5.68	.19	5	5.13	.15	2	2.00	.08
271.....	3	3.47	.19	6	7.33	.21	2	2.00	.12
272.....	7	8.42	.20	6	7.43	.20	6	7.62	.19
273.....	6	6.90	.21	4	4.92	.13	7	8.12	.18
274.....	4	4.32	.14			.07	1	1.01	.13
275.....	2	2.22	.10	2	1.84	.04	3	3.01	.04
276.....	3	3.00	.06	2	2.01	.06			.06
277.....			.05	2	2.12	.04	3	3.04	.03
278.....	2	2.00	.05			.09			.05
279.....	2	2.39	.07	5	6.07	.08	1	1.39	.04
280.....	2	2.39	.06	1	1.39	.08	2	2.40	.04
281.....	1	1.00	.05			.03			.04
282.....	1	1.39	.03	1	1.39	.01	1	1.39	.01
283.....			.01			.01			.01
284.....									
285.....			.03						
286.....	1	2.63	.03						
287.....			.03						
Totals...	2,647	3,099.94	99.91	2,836	3,200.04	99.94	2,652	3,099.95	99.95

[illegible]

TABLE VIII.—Body-length frequencies resulting from sampling weekly.—Continued.

Body length, millimeters	Trial A			Trial B			Trial C			Trial D			Trial E			Trial F		
	Actual.....	Weighted...	Smoothed, per cent..	Actual.....	Weighted...	Smoothed, per cent..	Actual.....	Weighted...	Smoothed, per cent..	Actual.....	Weighted...	Smoothed, per cent..	Actual.....	Weighted...	Smoothed, per cent..	Actual.....	Weighted...	Smoothed, per cent..
268.....	6	6.23	.43	6	6.66	.24	4	4.44	.14	4	4.52	.23	3	4.09	.16	5	5.46	.31
269.....	7	7.36	.38		4.13	.21			.09	1	1.00	.11	1	1.67	.13	3	3.12	.20
270.....	5	5.68	.30	4	4.66	.17						.05	1	1.00	.11	2	2.00	.13
271.....	2	2.00	.30	4	4.66	.27					1.47	.15	2	2.67	.20	2	2.00	.21
272.....	6	7.42	.30	4	5.18	.29	3	4.17	.08	5	6.42	.20	5	6.42	.21	6	7.62	.31
273.....	5	5.80	.30	4	4.92	.20	4	4.81	.20	2	2.49	.22	1	1.39	.15	6	7.11	.27
274.....	2	2.18	.18			.13	1	1.01	.15	2	2.14	.11			.03			
275.....	1	1.00	.12			.05	2	2.01	.06	1	1.22	.06			.02			
276.....	3	3.00	.08	1	1.01	.08			.02			.02	1	1.00	.04	1	1.00	.06
277.....			.10	1	1.12	.04	1	1.00	.02			.02	1	1.00	.04	2	2.04	.06
278.....	2	2.00	.09			.09			.05			.03			.10			.06
279.....	2	2.39	.13	3	3.40	.09	1	1.39	.07	1	1.39	.05	3	4.06	.11	1	1.39	.05
280.....	2	2.39	.09	1	1.39	.09	2	2.40	.07	1	1.39	.07	1	1.39	.11	1	1.39	.05
281.....			.07			.05			.07	1	1.00	.07			.05			.05
282.....	1	1.39	.03	1	1.39	.03	1	1.39	.03	1	1.39	.03	1	1.39	.03	1	1.39	.03
283.....			.03			.03			.03			.03			.03			.03
284.....																		
285.....			.05															
286.....	1	2.63	.05															
Totals.....	1,430	1,699.72	99.93	1,517	1,700.10	99.98	1,421	1,700.08	99.99	1,445	1,700.38	100.00	1,490	1,700.02	100.05	1,573	1,799.72	99.96

TABLE IX.—Length frequencies resulting from sampling twice a month.

Body length, millimeters	Trial A			Trial B			Trial C			Trial D			Trial E			Trial F		
	Actual.....	Weighted....	Smoothed, per cent...	Actual.....	Weighted....	Smoothed, per cent...	Actual.....	Weighted....	Smoothed, per cent...	Actual.....	Weighted....	Smoothed, per cent...	Actual.....	Weighted....	Smoothed, per cent...	Actual.....	Weighted....	Smoothed, per cent...
179.....	1	1.75	.03	1	1.41	.03	1	1.20	.02	1	1.02	.05	1	1.20	.02	2	1.82	.03
180.....			.03	2	2.17	.06	1	2.17	.06	1	1.20	.11		1.01	.05	2	2.13	.07
181.....			.07	3	2.28	.11	2	2.28	.15	3	2.90	.09		1.11	.07			.09
182.....	1	1.02	.10	3	3.67	.13	3	3.67	.17		4.10	.10		4.23	.11	1	1.01	.07
183.....	2	2.77	.11	4	4.28	.15	1	1.25	.13			.12			.18	1	.81	.11
184.....	1	1.75	.11	4	4.28	.15	1	1.25	.13			.12			.18	1	1.01	.11
185.....	1	1.12	.11	4	4.28	.15	2	2.56	.26			.19			.24	4	3.86	.16
186.....	2	2.98	.12	4	4.87	.23	2	2.56	.26			.19			.24	4	3.86	.16
187.....	1	1.12	.12	7	7.28	.26	4	7.28	.36			.35			.32	6	6.34	.32
188.....	6	7.79	.34	11	13.42	.48	7	9.27	.53			.47			.54	6	6.34	.32
189.....	8	9.36	.55	7	8.68	.72	10	11.98	.79			.62			.52	15	15.96	.52
190.....	11	12.54	.68	14	16.55	.87	17	21.47	1.10			.82			.74	5	5.26	.64
191.....	14	15.03	.78	18	21.50	1.11	17	21.47	1.10			.99			.74	14	13.48	.73
192.....	15	16.61	.93	19	22.13	1.44	20	25.92	1.45			.99			1.06	14	13.48	.73
193.....	19	20.72	1.14	28	33.32	1.60	29	30.79	1.67			1.27			1.57	19	20.62	1.20
194.....	21	26.20	1.41	40	46.21	2.43	33	33.31	2.04			1.78			1.83	31	30.94	1.66
195.....	27	29.51	1.53	45	51.47	2.42	40	46.21	2.43			2.08			1.97	38	38.33	1.78
196.....	23	26.87	1.74	46	54.63	2.47	45	51.47	2.42			2.16			2.26	25	27.06	1.95
197.....	31	37.70	1.92	41	48.18	2.71	39	33.19	2.43			2.41			2.40	38	37.79	1.94
198.....	34	38.77	2.25	38	43.78	2.73	40	43.93	2.60			2.54			2.55	44	44.77	2.47
199.....	38	45.21	2.58	35	39.79	2.58	41	49.84	2.74			2.36			2.59	47	50.91	2.50
200.....	46	53.31	2.58	44	52.61	2.71	49	54.57	2.71			2.24			2.51	38	39.20	2.30
201.....	33	41.09	2.52	35	41.69	2.43	38	42.04	2.71			2.68			2.81	32	33.86	2.36
202.....	35	41.56	2.48	44	52.61	2.70	43	48.13	2.73			2.49			2.61	47	50.90	2.62
203.....	44	51.47	2.44	44	52.61	2.70	43	48.13	2.73			2.55			2.72	42	42.66	2.60
204.....	31	40.05	2.44	45	51.55	2.89	45	51.55	2.88			2.46			2.91	44	48.11	2.71
205.....	30	34.04	2.34	50	58.01	2.80	32	34.89	2.68			2.34			2.89	45	48.11	2.71
206.....	37	46.04	2.04	32	37.04	2.44	38	40.74	2.46			2.46			2.91	43	43.49	2.42
207.....	31	37.70	1.87	31	37.16	2.10	29	31.41	1.95			2.23			2.61	30	32.10	1.97
208.....	24	31.20	1.66	25	27.10	2.01	24	27.30	1.61			1.95			2.30	23	25.90	1.59
209.....	25	34.77	2.04	39	44.24	2.03	26	28.36	1.59			1.37			2.06	25	27.88	1.35
210.....	33	44.11	2.08	34	38.40	1.73	28	30.20	1.37			1.24			1.62	16	19.17	1.37
211.....	28	33.12	1.95	25	28.15	1.75	18	18.94	1.37			1.24			1.51	24	26.80	1.41
212.....	29	32.71	1.70	25	28.15	1.53	17	18.93	1.43			1.24			1.51	27	29.97	1.46
213.....	23	26.49	1.68	23	26.49	1.33	21	24.43	1.43			1.33			1.53	20	22.22	1.48
214.....	28	32.75	1.73	23	26.49	1.33	22	26.47	1.43			1.33			1.70	25	27.95	1.41
215.....	24	28.62	1.56	17	19.83	1.09	16	18.14	1.09			1.33			1.68	23	26.08	1.53
216.....	17	20.15	1.15	18	21.89	.87	16	19.11	.87			1.11			1.69	26	28.75	1.45

TABLE IX.—Length frequencies resulting from sampling twice a month.—Continued.

Body length, millimeters	Trial A			Trial B			Trial C			Trial D			Trial E			Trial F		
	Actual.....	Weighted...	Smoothed, per cent..	Actual.....	Weighted...	Smoothed, per cent..	Actual.....	Weighted...	Smoothed, per cent..	Actual.....	Weighted...	Smoothed, per cent..	Actual.....	Weighted...	Smoothed, per cent..	Actual.....	Weighted...	Smoothed, per cent..
217.....	16	19.34	1.42	11	13.29	1.08	5	5.52	.93	15	16.11	1.57	19	22.87	1.72	20	23.32	1.50
218.....	23	30.80	1.34	21	21.45	.95	18	22.78	.85	32	39.90	1.62	24	35.36	1.61	24	28.93	1.34
219.....	18	22.27	1.30	11	12.74	.98	15	17.38	1.00	16	21.85	1.56	17	19.21	1.53	18	23.06	1.35
220.....	17	23.19	1.25	12	14.15	.98	12	13.90	.84	10	13.02	1.10	16	19.02	1.18	21	23.86	1.19
221.....	19	23.25	1.16	21	25.06	1.06	12	13.94	.79	14	18.16	1.16	13	18.51	1.26	18	20.12	1.24
222.....	14	17.26	1.14	14	16.91	1.08	13	14.62	.72	21	28.54	1.21	20	22.90	1.17	21	23.09	1.17
223.....	17	20.77	.92	13	15.60	1.01	10	10.62	.87	11	15.39	1.21	10	14.90	1.27	17	20.14	1.19
224.....	11	11.46	.85	19	22.05	.95	20	21.67	.78	16	18.28	.93	17	23.09	1.13	19	21.43	1.10
225.....	12	13.67	.63	12	13.80	.85	9	10.05	.75	11	11.07	1.03	14	16.29	1.12	15	17.87	1.10
226.....	8	8.90	.73	9	10.13	.72	8	8.71	.57	17	20.17	.97	13	14.30	1.00	13	14.76	.79
227.....	15	17.76	.76	13	15.04	.67	11	12.09	.52	14	15.13	1.20	12	17.58	.88	9	10.01	.75
228.....	13	14.54	.84	9	11.05	.62	7	7.28	.73	19	22.28	1.04	9	10.18	.88	12	15.58	.74
229.....	11	13.21	.74	6	7.23	.73	17	19.96	.79	12	12.80	1.14	10	14.37	.70	13	14.48	.68
230.....	11	12.22	.70	19	21.05	.74	14	15.38	.84	15	19.35	.85	8	9.09	.73	6	6.56	.72
231.....	12	12.52	.69	10	11.87	.89	9	10.12	.65	8	8.46	.83	10	11.37	.58	14	17.77	.61
232.....	11	12.73	.73	14	15.30	.69	9	9.36	.53	10	11.82	.71	7	7.64	.77	7	8.67	.89
233.....	13	14.09	.88	8	10.29	.84	8	8.93	.60	10	13.84	1.00	13	18.03	.92	16	21.52	.94
234.....	15	16.46	.88	17	19.49	.77	13	14.35	.78	18	22.46	1.09	16	18.58	.97	17	20.58	.90
235.....	15	16.98	.86	11	12.93	.74	17	18.99	.90	14	16.11	1.11	9	9.93	.71	8	11.54	.71
236.....	12	13.25	.81	8	8.03	.59	14	15.25	.85	12	14.57	.97	5	5.35	.65	11	16.25	.70
237.....	12	13.69	.79	10	11.38	.74	11	11.93	.76	13	15.90	.88	8	15.67	.62	8	10.65	.78
238.....	14	15.68	.78	10	10.80	.77	13	14.21	.70	8	11.83	1.08	8	12.45	.64	12	16.26	.78
239.....	12	12.74	.83	10	10.42	.77	11	11.73	.67	19	22.33	1.04	11	12.45	.64	10	11.29	.71
240.....	15	16.55	.83	10	11.53	.61	16	16.88	.72	15	17.67	1.30	8	9.35	.93	11	14.47	.98
241.....	19	20.34	1.06	11	11.54	.68	8	16.98	.89	17	22.34	1.24	17	22.79	.95	17	22.34	1.15
242.....	18	20.57	1.12	13	14.19	.70	18	20.90	.97	15	19.32	1.39	12	13.33	.87	20	25.22	1.25
243.....	18	19.54	1.03	11	12.05	.63	14	14.74	.83	21	25.33	1.13	14	15.51	.84	15	19.98	1.12
244.....	15	15.52	.91	7	7.82	.75	9	9.25	.69	9	9.49	1.04	10	11.42	.89	9	15.33	1.06
245.....	13	14.07	.86	19	20.85	.71	12	13.51	.68	12	15.08	.76	14	15.73	.94	17	22.09	1.22
246.....	15	16.68	.96	9	9.83	.97	13	14.06	.92	11	11.92	.84	13	17.88	.94	20	28.42	1.22
247.....	19	21.40	1.03	9	8.85	1.04	20	21.97	1.04	12	13.30	.76	10	15.10	.99	13	15.49	1.15
248.....	16	17.47	1.04	23	24.73	1.12	19	20.36	1.16	11	11.34	.84	13	14.65	.88	18	18.38	1.07
249.....	15	17.17	1.14	17	14.03	1.08	18	20.11	1.24	15	15.71	.99	11	12.28	.77	16	23.09	1.24
250.....	24	26.82	1.28	17	19.38	.83	24	26.36	1.14	20	20.39	1.15	9	10.20	.61	21	25.06	1.31
251.....	18	20.00	1.27	10	11.57	.86	18	20.18	1.24	17	19.16	1.26	6	6.80	.54	9	11.54	1.08
252.....	20	22.10	1.02	14	15.68	.75	13	14.70	.91	16	20.80	1.01	8	8.94	.47	7	11.52	.78
253.....	12	13.19	1.01	12	12.97	.88	13	14.26	.83	16	8.42	.76	6	6.87	.52	7	8.83	.85
254.....	18	19.33	.93	21	22.09	1.05	21	22.09	1.05	7	7.45	.53	8	9.09	.47	19	25.84	1.01

255	15	17.63	.94	14	16.00	.81	18	20.18	1.06	9	9.82	.49	6	6.73	.44	16	19.66	1.11
256	13	14.03	.85	13	8.79	.72	14	15.03	.91	6	6.26	.51	5	5.33	.53	12	14.43	.83
257	13	14.34	.74	13	14.16	.65	14	14.01	.77	8	8.45	.47	12	13.28	.61	10	11.01	.79
258	10	11.40	.74	11	12.24	.78	11	12.35	.71	8	8.05	.48	10	10.80	.66	15	17.40	.68
259	13	14.29	.77	14	15.92	.87	11	12.33	.72	7	6.70	.44	7	7.42	.62	7	8.47	.88
260	13	14.89	.83	17	18.89	.90	13	14.49	.68	6	6.38	.37	7	11.44	.51	18	21.77	.69
261	13	14.75	.76	13	13.94	.68	9	9.78	.55	5	4.68	.39	5	5.48	.42	6	7.16	.62
262	10	10.26	.58	4	4.03	.39	5	5.45	.34	7	7.44	.41	3	3.43	.33	4	4.68	.28
263	6	6.31	.55	3	3.00	.34	3	3.20	.37	7	7.49	.43	6	6.82	.30	3	3.18	.35
264	12	13.31	.65	10	11.17	.42	10	11.42	.46	4	5.87	.41	4	4.42	.28	8	10.77	.38
265	14	15.73	.63	7	8.17	.43	9	10.37	.50	5	6.50	.32	2	2.38	.19	5	6.35	.37
266	4	4.90	.67	3	3.78	.40	4	5.05	.44	3	2.84	.28	2	2.20	.17	2	2.78	.34
267	15	15.53	.58	9	9.78	.39	8	8.39	.33	4	4.22	.20	3	3.79	.13	9	9.43	.36
268	10	10.66	.60	7	7.44	.36	4	4.42	.28	3	2.84	.19	1	1.10	.15	6	7.10	.42
269	4	4.32	.30	2	2.00	.09	1	1.00	.16	7	2.04	.24	2	2.18	.07	5	5.97	.28
270	5	5.65	.32	2	2.00	.15	3	3.00	.13	7	6.69	.24	1	1.87	.08	2	2.00	.22
271	6	7.43	.31	4	6.17	.18	5	6.17	.28	3	3.01	.22	1	1.25	.06	3	3.67	.23
272	3	3.51	.22	2	2.40	.20	5	6.07	.23	3	3.41	.11	3	3.61	.13	5	6.62	.24
273	1	1.18	.12	3	3.15	.16	1	1.00	.13	1	1.00	.11	1	1.18	.14	2	2.43	.19
274	2	2.01	.13	3	3.01	.11	1	1.00	.04	3	3.05	.08	1	1.22	.12	1	1.18	.09
275	4	4.01	.15	2	2.12	.13	1	1.00	.07	3	3.05	.06	1	1.22	.05	1	1.00	.04
276	2	2.00	.04	2	2.00	.06	2	2.00	.06	1	1.00	.02	2	2.04	.02	2	2.04	.06
277	1	1.39	.07	1	1.39	.07	2	2.39	.08	1	1.00	.06	2	3.06	.09	2	3.06	.09
278	2	2.40	.09	2	2.40	.09	1	1.39	.07	2	2.01	.06	1	1.39	.08	1	1.39	.08
279	2	2.39	.09	1	1.00	.09	1	1.39	.07	1	1.39	.04	1	1.39	.05	1	1.39	.05
280	1	1.39	.07	1	1.39	.04	1	1.39	.05	1	1.39	.03	1	1.39	.03	1	1.39	.03
281	1	1.39	.03	1	1.39	.03	1	1.39	.03	1	1.39	.03	1	1.39	.03	1	1.39	.03
282	1	1.39	.03	1	1.39	.03	1	1.39	.03	1	1.39	.03	1	1.39	.03	1	1.39	.03
283	1	1.39	.03	1	1.39	.03	1	1.39	.03	1	1.39	.03	1	1.39	.03	1	1.39	.03
284	1	1.39	.03	1	1.39	.03	1	1.39	.03	1	1.39	.03	1	1.39	.03	1	1.39	.03
285	1	1.39	.03	1	1.39	.03	1	1.39	.03	1	1.39	.03	1	1.39	.03	1	1.39	.03
286	1	1.39	.03	1	1.39	.03	1	1.39	.03	1	1.39	.03	1	1.39	.03	1	1.39	.03
Totals	1,540	1,799.99	99.89	1,549	1,800.48	99.94	1,585	1,799.94	99.94	1,457	1,599.81	99.81	1,327	1,600.13	99.95	1,572	1,800.12	99.96

TABLE X.—Length frequencies resulting from sampling monthly.

Body length, millimeters	Trial A			Trial B		
	Actual	Weighted	Smoothed, per cent	Actual	Weighted	Smoothed, per cent
179	2	4.4	.06			
180	1	1.4	.06			
181	1	1.3	.05			
182			.15	1	1.8	.03
183	4	7.1	.27			.03
184	2	9.6	.39			.03
185	5	6.8	.44			.12
186	6	10.0	.42	1	1.8	.20
187	3	7.9	.47	3	5.3	.20
188	7	10.3	.74	2	4.5	.30
189	17	26.0	1.11	1	2.5	.35
190	14	30.4	1.30	5	10.6	.38
191	14	22.2	1.57	4	7.5	.42
192	30	41.6	2.19	3	5.3	.62
193	41	66.4	2.91	6	11.8	.68
194	43	65.4	3.39	10	20.1	.83
195	50	71.8	3.64	4	8.8	1.07
196	51	79.8	3.81	12	20.9	1.25
197	53	76.9	3.74	19	34.8	1.38
198	41	66.7	3.91	10	19.1	1.40
199	54	90.2	3.91	16	29.1	1.37
200	45	76.3	4.08	19	35.3	1.33
201	52	78.1	3.91	11	17.6	1.37
202	53	78.6	3.64	18	55.5	1.44
203	39	60.9	3.64	12	22.3	1.50
204	55	77.5	3.42	19	31.5	1.68
205	49	66.8	3.42	26	46.0	2.27
206	40	60.6	2.75	29	58.2	2.28
207	28	37.6	2.75	18	32.5	1.99
208	41	68.4	2.41	16	28.6	1.60
209	29	40.1	2.73	17	34.9	1.59
210	42	56.4	2.31	18	31.8	1.62
211	29	41.7	2.24	15	30.6	1.50
212	25	36.7	2.01	14	27.8	1.30
213	29	44.8	1.90	10	19.2	1.25
214	24	31.9	1.75	14	27.8	1.33
215	20	27.9	1.43	19	33.2	1.44
216	18	25.7	1.25	14	25.2	1.48
217	14	21.7	1.16	16	30.7	1.60
218	18	21.7	1.13	20	40.3	1.53
219	17	23.7	1.03	11	21.1	1.62
220	11	15.8	1.03	19	35.4	1.18
221	17	21.8	.76	9	14.8	1.30
222	6	7.6	.71	15	27.6	1.08
223	11	13.4	.59	13	22.2	1.23
224	9	13.9	.62	15	24.7	1.27
225	8	10.1	.49	17	29.0	1.27
226	5	6.0	.57	12	22.6	1.13
227	13	18.5	.59	9	16.8	.83
228	8	11.6	.69	6	10.7	.68
229	8	11.3	.57	7	12.8	.73
230	9	11.4	.52	14	20.0	.77
231	6	8.0	.57	8	12.9	.60
232	11	15.1	.52	3	3.0	.52
233	5	7.4	.52	10	15.2	.63
234	7	9.1	.34	12	20.0	.95
235	3	3.5	.27	15	21.6	.90
236	3	4.0	.20	9	12.5	.85
237	4	4.9	.20	11	16.6	.88
238	2	2.5	.20	19	23.8	1.00
239	4	4.6	.17	17	19.7	1.05
240	2	2.9	.17	13	19.4	1.10
241	2	2.3	.15	18	27.4	1.30
242	3	3.6	.25	21	31.4	1.43
243	7	9.0	.30	21	27.3	1.28
244	4	5.1	.34	15	18.2	1.27
245	5	6.4	.22	24	30.8	1.18
246	1	1.1	.20	16	21.9	1.55
247	3	3.9	.25	29	40.1	1.57
248	7	9.2	.30	24	31.6	1.60
249	4	4.0	.32	17	24.3	1.67
250	5	5.7	.22	30	43.9	1.67
251	2	2.3	.27	21	31.3	1.77
252	6	7.5	.20	22	30.8	1.45
253	1	1.4	.22	20	24.6	1.40
254	3	3.6	.15	20	28.7	1.37
255	3	3.4	.15	28	38.3	1.42

TABLE X.—Length frequencies resulting from sampling monthly.—Continued.

Body length, millimeters	Trial A			Trial B		
	Actual	Weighted	Smoothed, per cent	Actual	Weighted	Smoothed, per cent
256.....	1	1.3	.12	12	17.9	1.53
257.....	2	3.0	.12	20	26.3	.98
258.....	3	3.7	.30	11	15.0	.98
259.....	8	10.4	.27	14	17.3	.98
260.....	2	2.4	.27	17	26.3	1.18
261.....	3	3.5	.10	20	27.1	1.07
262.....			.07	9	10.3	.80
263.....	1	1.0	.05	8	10.3	.63
264.....	1	1.3	.12	11	17.0	.83
265.....	4	4.5	.15	16	22.3	.82
266.....	3	3.6	.20	6	9.3	.80
267.....	2	3.5	.15	11	16.9	.70
268.....	1	1.0	.15	12	16.0	.67
269.....	3	3.6	.12	5	6.7	.48
270.....	2	2.1	.12	4	6.0	.37
271.....	1	1.9	.07	6	9.5	.45
272.....			.05	7	11.6	.43
273.....	1	1.5	.05	3	5.0	.37
274.....	1	1.4	.07	4	5.7	.27
275.....	1	1.0	.05	4	5.3	.27
276.....			.02	5	5.0	.22
277.....				2	2.7	.15
278.....				1	1.7	.13
279.....				2	3.3	.15
280.....				3	4.3	.15
281.....				1	1.0	.13
282.....				1	2.3	.05
283.....						.03
284.....						
285.....						
286.....						
Totals.....	1,354	1,994.8	99.99	1,242	1,996.5	99.91

A STUDY OF FLUCTUATIONS IN THE SARDINE FISHERY AT SAN PEDRO

By
ELMER HIGGINS.

This paper is No. III of a series published by the Fish and Game Commission of California in Fish Bulletin No. 11, and is Contribution No. 54 from the California State Fisheries Laboratory. It was submitted for publication virtually in the present form in August, 1923.

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A STUDY OF FLUCTUATIONS IN THE SARDINE FISHERY AT SAN PEDRO.

By ELMER HIGGINS.

The present study of the fluctuations in the sardine fishery at San Pedro is presented as a part of the first installment in a comprehensive program of fishery investigations of the Fish and Game Commission, outlined elsewhere.

No pains have been spared to make the data upon which these studies are based, sufficiently detailed and extensive so as to be highly reliable. During the four seasons over 600 samples of the commercial catch have been taken containing over 17,500 specimens, which have all been measured and sexed and many of which have been weighed and observed for maturity, fatness, etc. During 1921, the collection of the samples and field notes, and the length measurements were made by Mr. Harlan B. Holmes, assistant. The collection and tabulation of the rest of the data together with its compilation and analysis have been carried out by the writer. Due to their extensive nature these data can not be presented in tables. These are, however, on file at the California State Fisheries Laboratory in San Pedro, California.

In order to study the fluctuations in the sardine fishery it has been necessary to collect extensive data at frequent and regular intervals as to the size composition of the catch. During the sardine

Methods of Collecting Data.

seasons of 1920 and 1921 samples of fish were taken daily when possible, but during the seasons of 1922 and 1923, the frequency of sampling was reduced to twice a week. Five samples per day were usually taken, each sample consisting of a perfectly random selection of twenty fish from a single boat load in 1920 and 1921, and of fifty fish in 1922 and 1923. The fish were taken directly from the boats on their arrival at the cannery docks, or from the conveyors while unloading, and data as to the locality and hour of the catch were recorded. The fish were then taken to the laboratory and carefully measured while perfectly fresh.

The best measure of the size of the sardine, the measurement least subject to seasonal fluctuation and the one most easily determined, is that of the *body length*. This length is the projection of the distance from the angle of the mandible to the end of the silvery area on the caudal peduncle when the scales are removed, and is the dimension referred to throughout this paper. This length was determined by placing the fish on a measuring board¹ parallel with the slide rod, with its nose pressed firmly against the nose block. The cross-wire was slid down until it was exactly over the edge of the area on the skin of the tail which is silvery when the scales are removed, and the length was read on a scale to the nearest millimeter. The fish were ordinarily flexible enough to lie flat on the board, but if *rigor mortis* was present, the fish were flexed in the hands until they could be straightened out. As a check for this length reading, the total length, or length from the snout to the end of the longest rays of the caudal fin (the lower

¹ The measuring board used was constructed similar to the one used by W. F. Thompson and figured in his report on the Canadian herring. See Thompson, W. F., Report British Columbia Commissioner of Fisheries, 1916. Victoria, B. C., pp. 39-87.

half), when pushed up into line with the axis of the body, was also read off and the two measurements recorded. These were later compared with a table constructed to show the "limits of variation" (three times the standard deviation) in the length of the caudal fin,¹ and if they failed to agree with the table, the whole record of that fish was considered in error and discarded.² Not many were so discarded.

The compilation of the data was guarded from error by every means. The length records of the individual samples were combined to make day-summary frequencies and checked by adding the unweighted lengths and balancing with the weighted sum of the length frequencies. The same check was applied in making week and month summaries. All the mathematical processes of smoothing, averaging, computing dispersion, etc., were likewise checked.

The region³ in which sardine fishing for the canneries is carried on in the San Pedro district extends along the coast for fifty or sixty miles, or from Santa Monica on the north to Newport Beach on the south, and out into the San Pedro Channel ten or fifteen miles. This area may, for convenience, be divided into three districts, one comprising Santa Monica Bay, another the waters offshore from Rocky Point to Point Fermin, and the third, San Pedro Bay and southeastward to Newport Inlet. See figure 1.

Sardine Fishing Area.

As may be seen by the chart, the physical character of these districts differs considerably. The east shore of Santa Monica Bay is a low sandy beach, broken by one tidal estuary which receives the land drainage of but a small area. The water is relatively shallow for a distance of several miles off shore, and the ocean floor inside the 100-fathom line is composed chiefly of coarse sand and gravel. A deep submarine valley cuts eastward to within a mile of shore at Redondo Beach and serves to separate this district from the second enumerated above.

The second district has a bold rocky shoreline extending from a few miles south of Redondo around eastward to Point Fermin. The rocky bottom out to a depth of ten or twenty fathoms provides suitable ground for dense beds of kelp, and beyond this the bottom shelves off abruptly into deep water, the 100-fathom line lying less than a mile from shore at Point Vincenti.

The third district—San Pedro Bay to Newport—resembles Santa Monica Bay in being shallow and having a low shore with sandy beaches. The bottom, of fine gray sand, however, has a gentler slope and is unbroken by submarine valleys, and drainage from a considerable area including the south slope of the Sierra Madre Mountains is received through several tide marshes. Thus, throughout the fishing area, shallow water and deep water alternate, and conditions of water temperature and currents no doubt contrast with equal sharpness.

By far the greater part of the commercial catch of sardines in the San Pedro region is taken over deep water in the middle district from Rocky Point to Point Fermin, although at times large hauls are made

¹ See page 6 of Mr. Sette's section.

² The sex of the fish and a rough determination of sexual maturity was made and recorded at the same time, and during 1921, observation on the weight of the body and the viscera, and on the fatness of the fish were made for other purposes.

³ See the first section by Mr. Thompson for a more general description and contrast with other fishing areas.

in the shallow water district from San Pedro to Newport, or in Santa Monica Bay. In the regular courses of taking sardine samples for measurement described elsewhere in this paper, inquiry was made of the boat captain, when possible, as to the locality in which his catch was made. It is believed that this information, general and faulty as it is, was given in good faith and is as reliable as the strenuous conditions of night fishing permit. From this information figure 1 was prepared to show the distribution of 154 catches of sardines made during the commercial fishing season, January 28 to April 30, 1921. These, of course, are but a small part of the total number of catches made during the spring season for the many canneries operating in the San Pedro district, but it is believed that the sampling is adequate to represent the conditions in the whole district.



FIGURE 1. Map of regions in which sardine fishery is carried on from Los Angeles Harbor, and the location of certain catches made in 1921 (Season of 1920-21).

- A. Santa Monica Bay.
- B. San Pedro Channel.
- C. San Pedro Bay.

- 1. Santa Monica.
- 2. Redondo.
- 3. Rocky Point.
- 4. Point Vincenti.
- 5. Portuguese Bend.
- 6. Point Fermin.
- 7. Los Angeles Harbor (San Pedro and Wilmington).
- 8. Long Beach.
- 9. Newport.
- 10. Catalina Island.

The abundance of sardines in different localities apparently differs from year to year, if the relative frequency of catches is significant. The following table gives the number of catches in each of the three districts in per cent of the total number for which

Changes in the Fishing Localities.

locality records were obtained during the four seasons:

Catches of Sardines Made in Each Locality.

Year	Santa Monica Bay		Rocky Point to Point Fermin		San Pedro Bay to Newport		Total No.
	No.	Per cent	No.	Per cent	No.	Per cent	
1920 -----	5	4	85	71	30	25	120
1921 -----	23	15	121	79	10	6	154
1922 -----	21	38	35	62	--	--	56
1923 -----	35	29	83	69	3	2	121

While it is evident that the bulk of the catch comes from the middle district it can be seen that the catches in the other two districts vary in importance, and also that there is an apparent shift of fishing from the eastern district toward the west from 1920 to 1922.

Many fishermen are of the opinion that smaller fish are caught more generally in the San Pedro Bay district than in the deep water from Point Fermin toward Redondo, but our data does not include a long enough series of comparable catches upon which conclusions may be based. The two cases of roughly comparable records show the following average sizes:

	Rocky Point to Point Fermin		San Pedro Bay to Newport	
	No. samples	Average length	No. samples	Average length
February, 1921 -----	42	228 mm.	28	210 mm.
March, 1922 -----	64	208 mm.	10	198 mm.

In so far as this goes the opinion of the fishermen is supported.

It is also the popular belief that catches of fish of more uniform size are made in the two eastern districts than in Santa Monica Bay. Fishermen believe that as a rule schools of fish of small¹ and uniform size frequent the shallow waters from San Pedro Bay to Newport, that fish of larger uniform size are found in the deep water about Point Vincenti, but that mixed sizes may be taken at any time during the spring in Santa Monica Bay. A study of the dispersion of sizes in the individual loads landed from the three districts in 1920 shows an average *coefficient of variability*

$$(\text{Pearson ; } V = \frac{\text{standard deviation}}{\text{mean}} \times 100)$$

for Santa Monica Bay district of 8.27, based on eleven loads; for Rocky Point to Point Fermin, 6.51, based on nineteen loads; and for San Pedro Bay to Newport of 5.32, based on twelve loads. In other words, there was on the average, a greater diversity of sizes of fish in each boat-load landed from Santa Monica Bay in 1920 than from the other two fishing areas about San Pedro, this evidence again coinciding with the opinion of fishermen. It is possible that the greater dispersion in sizes in the individual boat loads from this region is due to the diversified character of Santa Monica Bay and to the fact that, on the average, two or more hauls are necessary to obtain a suitable amount of fish for a load from any district. In passing northward along the coast, the fishing boat passes over the deep submarine valley near Redondo and then into shallow water in a very short time, and hauls one mile apart may be made over depths ranging from 10 to 100

¹ "Small" as used by the commercial fishermen at San Pedro denotes sardines of 18-20cm. in body length. "Large" sizes are from 23-26cm. in body length and both are canned in oval 1-lb. cans.

fathoms. Such conditions do not exist in either of the other localities and the individual hauls forming parts of the loads are not likely to differ thus markedly.

There is no clear evidence, as seen in the following table, however, that the total dispersion of all fish in each district differs in any regular way. The *coefficients of variability* of all the fish in comparable loads in each locality vary from month to month in the different years in an irregular fashion, making it impossible to determine the relative uniformity of sizes in the fishing area, when each district is considered as a whole.

Dispersion of Sardines in Comparable Periods According to Locality of Catch.

(Based on summed frequency of all fish in the period and district considered.)

	Santa Monica Bay District			Pt. Vincenti District			San Pedro Bay District		
	No. samples	Av. size	Coeff. of Var.	No. samples	Av. size	Coeff. of Var.	No. samples	Av. size	Coeff. of Var.
1921									
Feb. -----	8	205.3	14.63	8	234.4	6.78			
Mar. -----	9	200.6	10.20	10	207.4	9.11	8	207.4	9.82
1922									
Feb. -----	10	226.4	9.45	9	219.4	9.94			
Mar. -----	6	228.4	8.49	8	226.4	9.72			

As to locality changes from month to month within the season, little can be said, since the shift from district to district is so irregular as to require a long series of records in which to detect the trend. It is apparent, however, from the following table, that during 1921, 1922, and 1923, there was a marked tendency to fish farther and farther from shore as the season progressed. April, 1921, is the exception to this

Average Distance From Shore of Sardine Catches.

	1921		1922		1923	
	Distance miles	No. records	Distance miles	No. records	Distance miles	No. records
Jan. -----	3.2	18	2.6	18	3.6	24
Feb. -----	3.5	51	4.2	31	3.6	35
Mar. -----	5.9	82	5.6	14	6.2	25
Apr. -----	3.7	56	---	---	---	---
Dec. -----	---	---	6.4	37	---	---

trend, but it is interesting to note that a high percentage of these April fish were "spents"—the first to be taken in quantity during the season. Can it be that the fishermen actually follow a seaward spawning migration during March and meet the returning "spents" in April?

But these indications of movement are conditioned by other problems in the biology of the species such as spawning and its success or failure, and adjustments to physical environment. If actual localization in the ocean according to size does exist, it may well be that shifting of the fishing ground may depend upon the appearance, growth, and passing of an abundant year-class.

When investigation of the sizes of sardines was started at San Pedro in December, 1919, it was found that fish ranging from about 70 to 275 mm. in length were taken by commercial fishermen. Later both larger and smaller sizes were taken, so that the range in size of sardines taken with the regular gear may be said to be from 50 to 285 mm., body length, or from about 2 to 11¼ inches.

The Sizes of Sardines
at San Pedro.

Practically all of the commercial catch is utilized by the canning industry and consists chiefly of fish over 180 mm. in body length which are canned in one-pound oval tins. Little demand exists at San Pedro for the smaller sizes usually canned in one-quarter-pound tins after the French method, and when catches of small or mixed sizes are inadvertently made, the fish are, as a rule, converted into fish meal for use as fertilizer. A relatively small quantity of the smaller sizes are sold throughout the year in the fresh fish markets for use as bait in other fisheries or for consumption in a fresh condition.

Besides the commercial sardine fishery, there is the summer bait fishery which uses considerable quantities of small sardines as bait in catching albacore, tuna, and skipjack. Sardines ranging from 100 to 180 mm. are caught from June to October by the fishing boats before proceeding to their grounds, and a study of samples obtained during this period has yielded valuable results to be presented at a future time.

Not all of these commercial sizes, however, are available at the same time. The larger fish (over 180 mm.) appear in December, in quantity,

Fishing Season.

and remain until May, when they disappear from the catches and do not reappear except in small numbers until the following winter. The smaller fish apparently remain near shore throughout the year, and become the object of the summer bait fishery.

But the period during which the adult sardines are present in the catches is quite variable, judging by the duration of the commercial canning season, and the character of the run is equally uncertain. Canning in 1919-1920 began about the end of November with only very small sizes ("quarter oils") available. By the end of December, larger sizes were running and operations on these sizes continued in a few canneries till toward the end of April. The following season was delayed by economic difficulties and when canning began in the last week of January, 1921, large fish were abundant and were taken in varying quantities until the end of April. The 1922 season was short, lasting only from about January 20 to the middle of March, although some operations continued into April. The season of 1922-23, however, contrasted with former ones by opening in the third week of November with an abundant run of small adult fish ("pound ovals") which lasted well into January. In January the larger sizes appeared and extensive canning continued until early in April.

As has been suggested, the sardines taken throughout a season are not of uniform size, but, as in other fisheries, fluctuate widely from day to day and from month to month, in size, quality and abundance.

Let us, then, consider the character of these fluctuations and discover, if possible, their significance.

The average size of fish landed at the canneries within the limits of commercial sizes varies from day to day throughout the season, with little apparent regularity. The range in average size has been as great as 110 mm. or from 150 to 260 mm. in length. The majority of the samples, however, have a mean length between 200 and 250 mm.

Size Fluctuations of Sardines in the Commercial Catch.

Not only do the daily means vary greatly, but there are wide differences between the average sizes of different loads landed on the same day. On some days the fish landed are of quite uniform size; on other days practically the entire

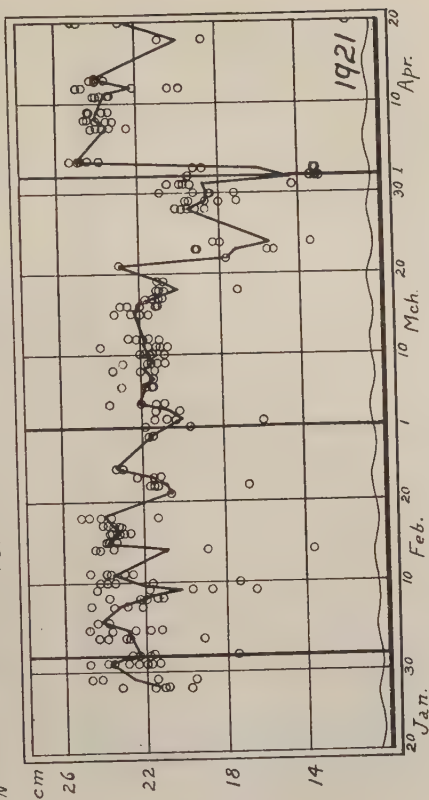
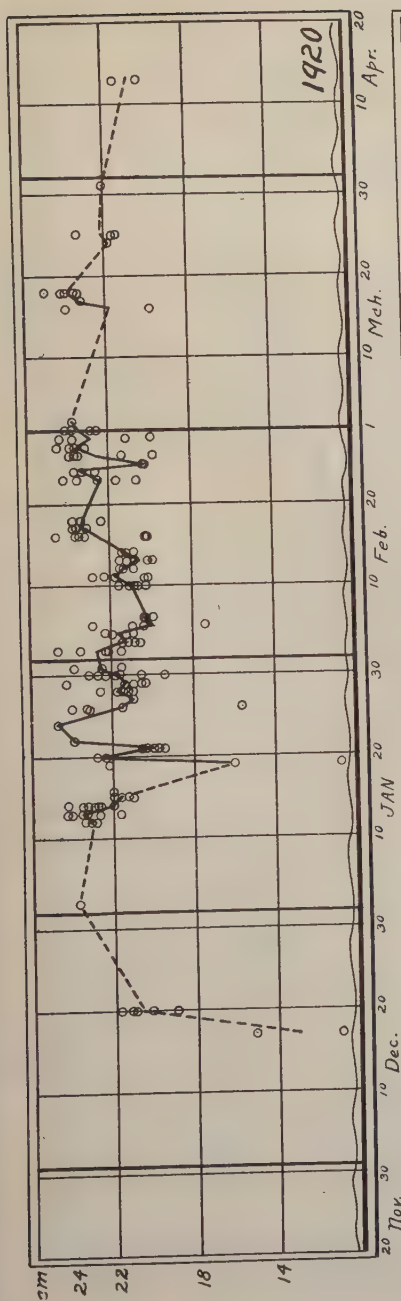


FIGURE 2. Fluctuations in the average size of sardines in the commercial catch at San Pedro during the season of 1919-20. Circles: mean length of fish in individual samples. Points of lines: mean length of all fish sampled each day.

FIGURE 3. Same for 1921. (Season of 1920-21.)

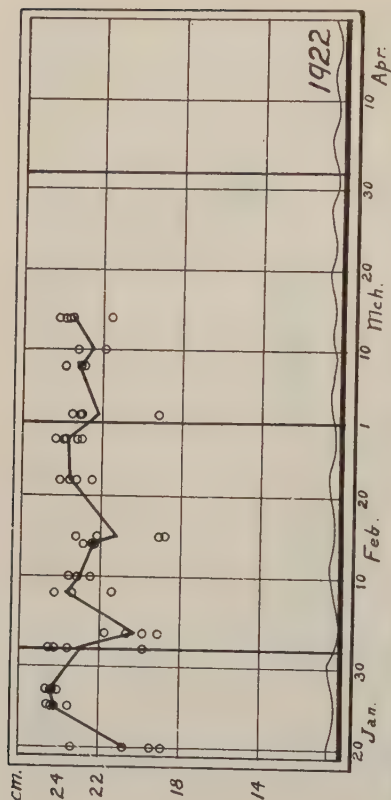


FIGURE 4. Fluctuations in the average size of sardines of both sexes in the commercial catch at San Pedro during the season of 1921-22. Circles: mean length of fish in individual samples. Points of lines: mean length of all fish sampled each day.

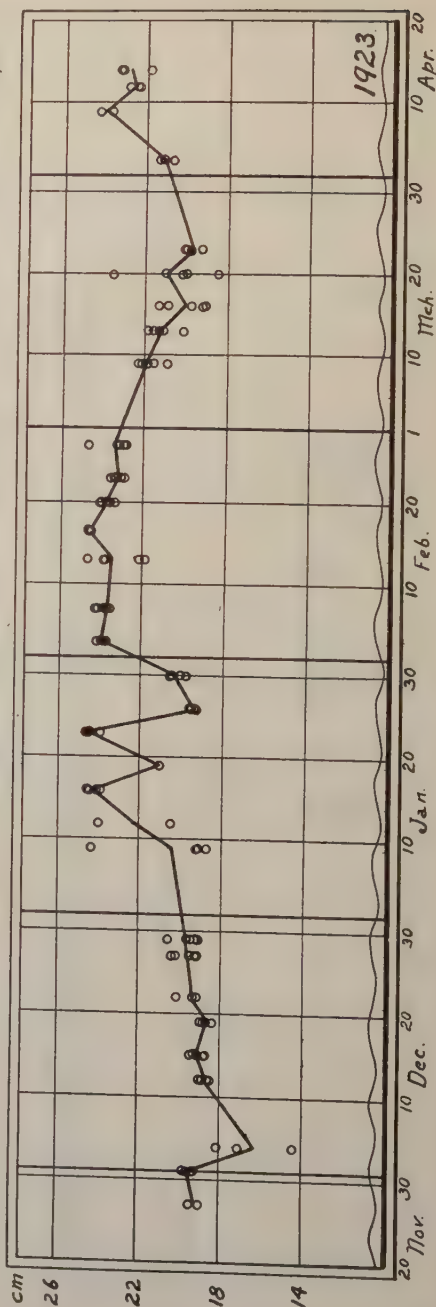


FIGURE 5. Same for 1922-23.

range of useful sizes are represented. Figures 2, 3, 4 and 5 are the graphic daily records of the average sizes of the fish during the commercial seasons. Each circle represents the mean length of the fish in a single sample, and the line represents the daily average length, each sample being weighted equally in determining the value.

But this daily variability in size is not particularly surprising when the many factors which produce or influence it are considered. Such factors as the wandering into or out of the fishing area of schools of differing size or age composition, the wide extent of the fishing area with its varying hydrographic and other physical conditions together with the factors of chance governing the success of the discovery and capture of schools of various sized fish, all tend to increase the dispersion of sizes of fish landed. Opposing these, and tending to make the catches more uniform within the day are such factors as the more general influence of weather conditions, and selection of sizes by the gear and by the fishermen on account of varying visibility or cannery demand. The habit of the fishermen of flocking to a locality in which abundant hauls had been made on preceding days might also tend

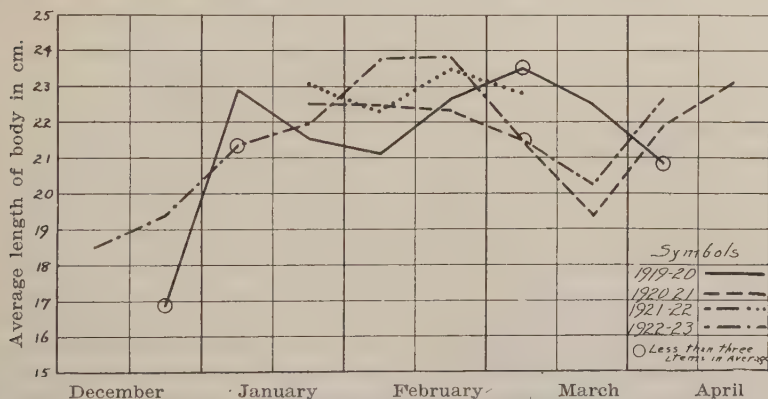


FIGURE 6. Fluctuation in average length of sardines taken at San Pedro, averaging all individuals taken in two-week periods.

toward greater uniformity of size. Whatever selective influences may operate, however, such as selection by gear or by cannery demand, they probably are sufficiently constant to leave a residue of significant variations which may be studied biologically. Thus it is plain that the shifting of sizes is a complex reaction to many influences and an understanding of its meaning must rest upon a great number of observations made in various fields of scientific inquiry.

Although our observations are inadequate to demonstrate a regularity of short-time fluctuations in the sizes of sardines they are sufficient to indicate the general trend throughout the different seasons. Figure 6 shows the trend for the four years covered by our records, calculated from the daily means by averaging in fifteen day periods. Every curve is based upon the original data, and a comparison of figures 2 to 5 and the table on page 137 will indicate the extent to

The Monthly Trend in Average Size.

which these original observations are lacking. The reliable sections of the curves indicate that the maximum sizes are taken during February, preceded and followed by smaller sizes, although large fish again appear in April. The monthly averages of the daily mean length throughout the seasons are shown in the following table:

Monthly Average Lengths of San Pedro Sardines in the Commercial Catch.

	1919-1920		1920-1921		1921-1922		1922-1923	
	No. days	Av. lgth. mm.	No. days	Av. lgth. mm.	No. days	Av. lgth. mm.	No. days	Av. lgth. mm.
Dec. -----	---	---	---	---	---	---	8	189.6
Jan. -----	16	219.1	3	225.0	3	203.8	7	217.8
Feb. -----	19	218.5	19	224.2	8	226.4	7	237.9
Mar. -----	8	227.5	24	204.7	4	228.4	5	207.7
Apr. -----	1	208.4	13	222.6	---	---	4	226.5

Attention is called to the increasing value from year to year of the February averages. This fact and its significance will be discussed later.

A more accurate picture of the actual size-changes of fish in the commercial catch may be obtained from a study of the length-frequency curves. These curves were obtained by adding together the frequencies of fish in millimeter length units for a month

Monthly Fluctuations in Size-composition of the Commercial Catch. or similar period and smoothing the resulting frequencies by a moving average of threes applied twice. The individual samples (one from each boat load) were given equal weight each day by multiplying the actual frequencies by a factor

which would bring the sums of the frequencies in each sample to the same number. During 1920 and 1921, each sample was weighted to 20 fish, and during 1922 and 1923, to 50 fish each. Further, each day was given equal value in the month summary by weighting in a similar way to 100 fish daily. Thus since each day's samples contributed equally to the month's curve, the result may safely be considered as representative of the period in which the catches were made. Error due to massing observations irregularly in different periods has been largely avoided, as reference to the following table of dates of sampling shows, and the record, therefore, except in certain months, is highly reliable.

Number of samples taken at San Pedro, according to days of months (1919-1923).

Days	Dec, 1919--	Jan, 1920--	Feb, 1920--	Mar, 1920--	Apr, 1920--	Dec, 1920--	Jan, 1921--	Feb, 1921--	Mar, 1921--	Apr, 1921--	Jan, 1922--	Feb, 1922--	Mar, 1922--	Dec, 1922--	Jan, 1923--	Feb, 1923--	Mar, 1923--	Apr, 1923--
1.								4	2	5		4		4				
2.		1	5	4					2	5			4			5		
3.			5				1	5	2	4		4						5
4.			4				1	5	4					3				
5.			4				1	1	2									
6.			5				2											
7.							4	1							5			
8.							5	5	5		2	4						
9.							5	5	5					4		5	2	
10.			5				1	5	6			3	2					
11.			5				1	5	5	5								
12.		4	3				2		5	5				5	2			3
13.		8	5				2		5	5						5	5	
14.		7	3		2		2											
15.		5					2	5				3	5					3
16.			6	2		1	2	3	6					5				
17.	2		3	1			2	5	5			4			4	5	5	
18.			4	5				5										
19.		3					1		2	2					4	1		
20.	5	2					1		6	4								
21.		5						1	1	3	4					5	5	
22.		1						5	1	4		4		4	4			
23.			5					5	4							5	5	
24.		1	3				2	2	5									
25.			2	4							5							
26.		4	5		1		1								5			
27.		1	5								5					5		
28.		6	4				5	2	5			5						
29.		7				1	4		5	1				5				
30.		8							5	1					4			
31.		3		1			5		5									

There are grounds for considering the natural period for the studying of size fluctuations to be the lunar instead of the calendar month. At San Pedro, fishing, during the few days before and after the full moon, is carried on in the day time, while during the dark phases of the moon, night fishing is practiced exclusively. It is the belief of the fishermen that smaller and more valuable sizes of sardines are obtained during the full moon period, and although brief analysis of our data does not entirely corroborate such a belief, it may well be that a definite size-fluctuation according to the lunar or some other synchronous cycle really exists. In order to represent the changes fairly, the data must be divided into similar periods. Moreover, at Monterey fishing stops at the full moon period and regular breaks in the record are therefore unavoidable. Accordingly it was decided, in order to make the records from San Pedro and Monterey directly comparable, to group the data in lunar periods beginning with the day of the full moon.

Figure 7 shows the length-frequencies of sardines in the commercial catch at San Pedro according to lunar months.¹ Here may be seen more clearly the shifting of sizes from month to month.

By a comparison of these curves it is apparent that larger sizes are more abundant in the first lunar month of the main commercial season than in the second. A shift in importance of two relatively abundant size-groups seems to exist between the first and second lunar months of the season. Thus in 1920 (season of 1919-20) the weight of abundant

¹We have elsewhere designated the winter season by the combination of two years, for example: 1920-21, but the lunar periods dealt with here fall in January or later of the year 1921.

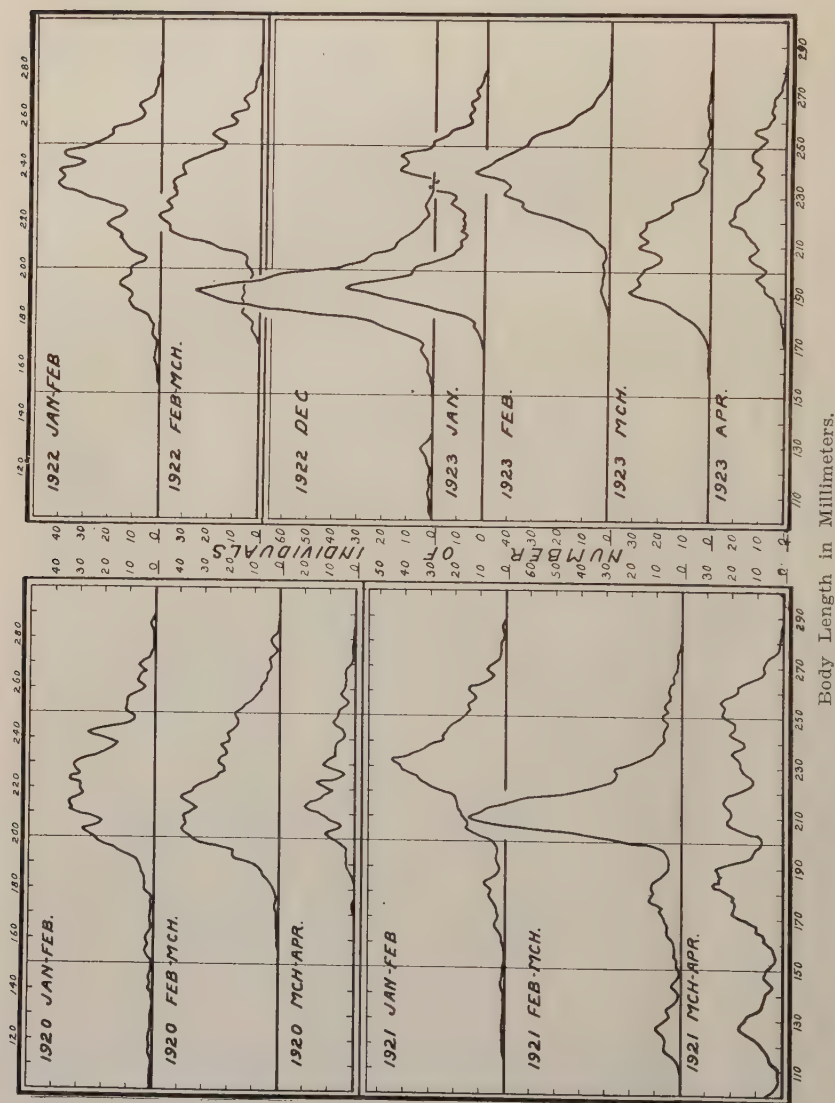


FIGURE 7. Size-frequencies for both sexes for combined samples taken during lunar months of commercial fishing season. Lunar months indicated by calendar months within which they fall.

sizes shifted from 220 mm. in the first period to 205 mm. in the second; in 1921 the shift was from 230 mm. to 210 mm.; in 1922, from 240 mm. to 220 mm.; and in 1923, from 240 and 245 mm. to 230 and 240 mm. The run in 1923, of course, contrasted with that of previous years in the presence of a much smaller group of fish about 190 mm. long, but the change of the larger fish is practically the same as that of previous years.

This shifting of sizes in the larger fish is beyond doubt a part of the seasonal trend as shown by the daily average sizes and in figure 6, and the apparent discrepancy between the curves of the average length and those of length frequencies is due in part to the shifting of the lunar in relation to the calendar month. When the second lunar month falls later in the season, as in 1921, the shift from large to small fish is more pronounced, but when it falls earlier, as in 1920 and 1923, the shift is less striking.

The third lunar month, or the latter part of the season—March and April—is apparently characterized by both large and small fish. In 1921, all sizes within the range of commercial use were landed, and in 1923 (season of 1922–23), all sizes of adult fish were taken.

Periodic changes of several years duration can not, of course, be determined in so brief a time as has passed since the sardine investigations began at San Pedro, but differences between the years may be

Long Time Size Fluctuations.

studied and the trend and its possible significance may be noted. Figure 8 represents the total frequencies of all fish in our samples landed at canneries during the commercial seasons of 1920–1923. Each curve was made by adding the lunar month length-frequencies, weighted and smoothed, in which each day's record is equally represented; and because of the disparity in numbers in the different year-totals, the frequency at each length-unit was reduced to a percentage of the total number.

A comparison of these curves shows many differences in the sizes of fish in the four seasons. In 1920, a considerable group of sardines about 200 mm. long was taken which was practically lacking from the catches of 1921 and 1922, and the 210 mm. group which was the most important in 1921 was poorly represented in 1922 and 1923. But fish 230 mm. and above increased in relative numerical importance yearly throughout all four seasons. Indeed, there is an evident shifting from smaller to larger sizes from year to year except in the last, in which a numerous group of small fish appears. In 1923, however, there is a distinct gap in the length series between the larger and smaller fish, making it easy to assume that these large fish are from the same year-class as the larger group of the preceding years, and that the smaller fish, being much younger, are appearing for the first time among the commercial sizes.

This yearly increase in the sizes of the fish in the commercial catch is so consistent and regular that it appears to be a phenomenon of the growth of the component age-groups.

The annual change in the size composition of the commercial catch is at once suggestive of the phenomenon of *dominance* of certain year-classes as demonstrated by Hjort and others in the herring and cod

Significance of
Yearly Size
Fluctuations.

fisheries of Norway. Great variations in the total yield and the size composition of these fisheries have long been recognized, but Hjort showed that the increased yield and the increase in average size of fish in the years just preceding

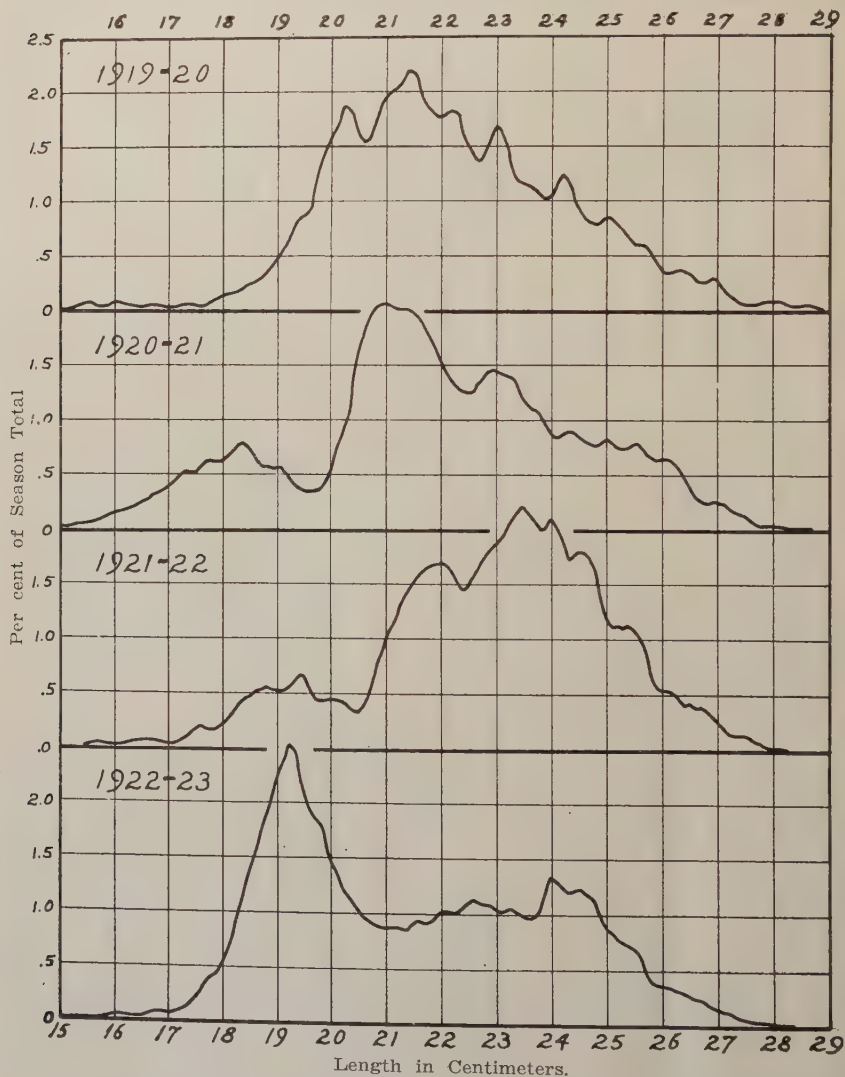


FIGURE 8. Size frequencies for individuals of both sexes examined during each commercial season at San Pedro from 1919-20 to 1922-23, expressed for each millimeter as per cents of the total number of individuals examined each season.

1914 were due to the appearance and growth of a particularly abundant year-class, that of 1904. These facts lead him to the conclusion:¹

¹Hjort, Johan, 1914: "Fluctuations in the Great Fisheries of Northern Europe viewed in the light of Biological Research."

Rapp, et Proc.-Verb. Cons. Perm. Intern. Explor. Mer, Vol. XX, p. 202. (Copenhagen, 1914.)

"The study of methodically collected material, embracing a period of many years, has demonstrated the existence of an intimate relation between the fluctuations in the numerical value of the stock of fish and the yield of the great fisheries. * * *

"The opinion generally prevalent hitherto was that the renewal of the stock of fish took place, as in the case of the increase of any human population, by means of a more or less constant annual increment in the form of new individuals; the results here arrived at, however, indicate that this renewal, in the case of the species investigated, is of a highly irregular nature. At certain intervals year classes arise which far exceed the average in point of numbers, and during their lifetime, this numerical superiority affects the general character of the stock, both as regards quantity and quality, thus again exerting a decisive influence upon the yield of the fisheries in both respects."

In the Norwegian investigations, the evaluation of various year-classes was based upon an age-assessment of samples by means of scale readings upon the individual fish. In the present case, however, such a method is impractical, and a judgment of the relative importance of year groups must rest upon other lines of evidence. There exists, however, a chain of circumstances, which, we believe, provides a more or less adequate proof of the existence, in the case of the California sardine, of an irregularity in the annual increment of new individuals similar to, although probably less extreme than that of the Norwegian herring.

There are several general propositions upon which our argument rests:

1. Our data from which all our evidence is drawn is sufficiently representative of all sardines in this region.

2. Strongly marked modes and troughs appear in the curves of length-frequency distribution; such modes, particularly among smaller fish, indicate the mean or modal lengths of particular year-classes, or combinations of year-classes.

3. Certain size groups definitely marked by the abundance of the component individuals, may be identified year after year in the total frequency curves, and these modes, and equally marked troughs, progress along the size scale, year by year, in a manner which simulates a normal growth rate.

4. A new mode composed of smaller fish appears, which is apparently a new and abundant year-class just arrived at commercial size.

(1) The only means of judging the truth or falsity of our first proposition, that our data are an adequate representation of all fish in this region, is that of continued trial. There is no absolute mathematical criterion of adequacy of sampling in such a case since the conditions of the fishery for each species are unknown factors. (See Sette, page 91.) However, consistency of results over a long period would undoubtedly indicate adequacy of data and such can only be established by time. (See Thompson, *Errors in Methods*, page 189.) A detailed consideration of the adequacy of our systems of sampling, however, is given in another section of this bulletin, and on the strength of such analysis we feel safe in making the fundamental assumption that changes indicated by our data actually represent changes in the fish population.

(2) Ever since the pioneer work of Petersen, the great Danish biologist, upon the age assessment of fish by means of plotting the frequency of the various length measurements, it has been recognized that, especially among the younger fish, there is a perfectly obvious relation between age and length and that the various length groups which exist in the plotted curves, represent different age-groups or year-classes. Petersen's method rests upon the supposition that the superiority in the size of the fry of one year's spawning over those of the succeeding year is maintained during the life of the fish. But if this were entirely true the method still could not be applied to the older age-groups since, due to the naturally decreasing growth rate, the yearly increment in length soon becomes less than the individual size differences within a year-class, and the size-groups, instead of remaining distinct as in the younger fish, become amalgamated into one complex group in which the different ages are by these means indistinguishable.

Thus, when the length-frequencies of the California sardine in the winter months (e.g. January) are plotted, there appear several distinct modes—one at about 100 mm., one at about 150 mm., one at about 185 or 190 mm., etc. The first group is entirely segregated from the next, but the second is connected with the third by a scattering of individuals of intermediate length. Likewise the limits of the third group are indistinct particularly on the side of the larger fish because of the presence of considerable numbers of fish of intermediate length which can not definitely be assigned to either group. These evident groups we believe to represent separate year-classes with modes representing more or less accurately the modal or average lengths of the corresponding age-groups.

But the modes which appear among the larger fish (220 mm. up) may have a somewhat different significance. Thus, the next mode, that somewhere above 200 mm., is probably made up, to quite a considerable degree, of fish belonging to one or more still older age-groups, the numerical importance of which we have no means of judging. If we were warranted in assuming that the various year-classes with known dispersion were represented by individuals uniformly decreasing in number with age, it would then be possible to construe with greater certainty a significance of position to each mode; but since the year-classes are probably present in highly varying proportions, only the most general conclusions may be drawn as to modal lengths of the various age-groups. If a prominent size-group is composed of representatives of a numerous year-class and a sparse one, the mode of the group will lie at that of the numerous year-class and all evidence of the sparse one may be hidden unless a high degree of symmetry is present in the frequency distribution of the numerous age-groups. But the relative importance of different year-classes, in the commercial catch may, and probably does, vary from month to month during the season, for the modes among the larger fish in the frequency curves fluctuate quite irregularly in position at different periods.

However, certain modes are sufficiently consistent in position throughout whole seasons that they may be accepted as representing the composition of the whole stock, and as such may be considered useful evidence in the present problem. It is natural to assume that any well marked mode, especially when separated from the rest of the

curve by an equally marked trough, marks the most probable position of a more abundantly represented year-class; they will not be so called, however, but, with all the foregoing reservations clearly in mind, will merely be referred to as size-groups.

(3) In the season frequency curves (figure 8) certain modes are marked by the abundance of the component individuals and their position in relation to other modes or troughs, and may be identified year after year in positions which advance along the size scale. Thus, the mode at 202 mm. in 1920 (season of 1919-20) is present in 1921 at about 210 mm., in 1922 at about 220 mm., and in 1923 in the high portion of the curve between 220 and 230 mm. Although the next mode in 1920 can not be clearly traced, a mode in 1921 at 230 mm. is present again in 1922 at 235 mm., and in the following year at 240 mm.

Males.

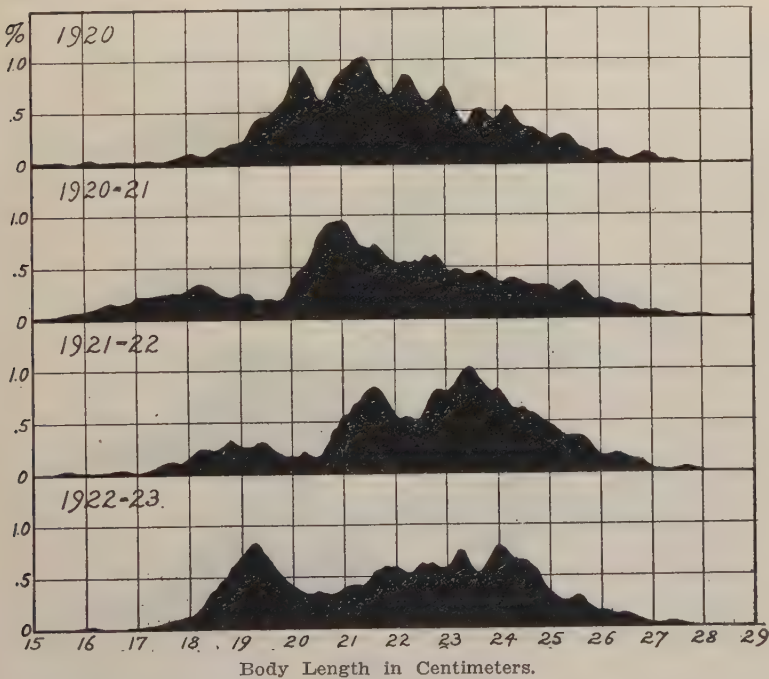


FIGURE 9. Size frequencies of males examined during commercial seasons at San Pedro from 1919-20 to 1922-23, expressed for each millimeter as per cents of the total number of both sexes examined each season. Season of 1922-23 from January to April.

The same annual movement of the two most prominent size-groups along the size scale is also seen when the length-frequency data of the different seasons are broken up into various parts. Thus, the curves of the two sexes considered separately for each season show almost the same results. Figures 9 and 10 represent the frequencies of the males and females respectively in our samples of the commercial catch of each season expressed in per cents of the total number of both sexes. In the curves of males, the first prominent mode appears in the different years at 202, 210, 216, and either 220 or 226 mm. In the curves of

females, the same progression is seen, the first prominent mode appearing in the different years at 202, 211, or 213, 221 and 224-228 mm.

An equally striking feature of the progression of the size-groups is the corresponding movement of the troughs or gaps in the frequency curves. Referring to the season curves of males again, it may be seen that the depression at about 190 mm. in 1920 progresses to 198, 205, and 213 in the following years; and in the curves of females, the progression is from 190 mm. or less to 197, 205, and 212 or 217.

It may be noted in passing, that the position of these troughs is remarkably consistent in the two sexes, but that the corresponding modes vary considerably, those of the females being uniformly higher on the size scale than those of the males. This is an evident characteristic of a kind of sexual dimorphism which exists in the California

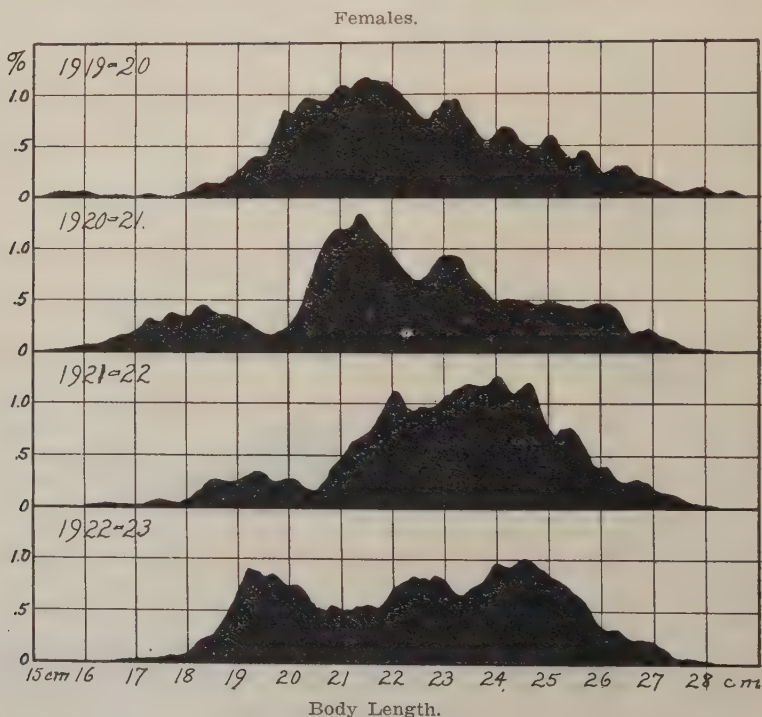


FIGURE 10. Size frequencies of females examined during commercial seasons at San Pedro from 1919-20 to 1922-23, expressed for each millimeter as per cents of the total number of both sexes examined each season. Season of 1922-23 from January to April.

sardine. In any year-class, especially among older fish, the females apparently have a greater mean size than have the males, and this difference increases with increasing age.

As further evidence of the progress of the various size-groups, the data are presented from shorter time periods, and on account of the size difference between the sexes, males and females are considered separately. Lunar months are natural units, as before mentioned, and observations are numerous enough to provide reasonably accurate results, but because of the reduced period and smaller numbers of fish,

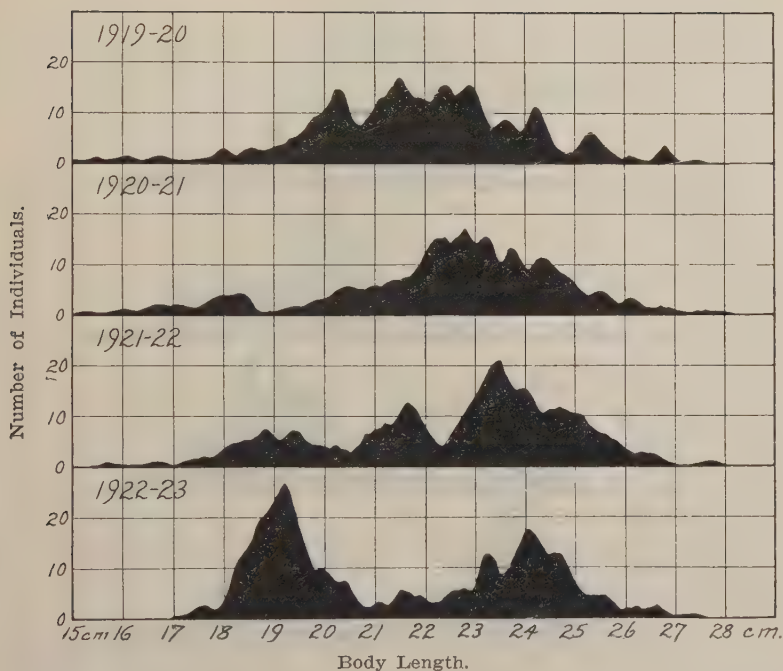


FIGURE 11. Size frequencies of males examined during first lunar period of each commercial season at San Pedro from 1919-20 to 1922-23, expressed as numbers of individuals at each millimeter of body length. Lunar periods occurred as follows:

1919-20—January 5, 1920, to February 4th.
 1920-21—January 23, 1921, to February 22d.
 1921-22—January 13, 1922, to February 12th.
 1922-23—January 3, 1923, to February 1st.

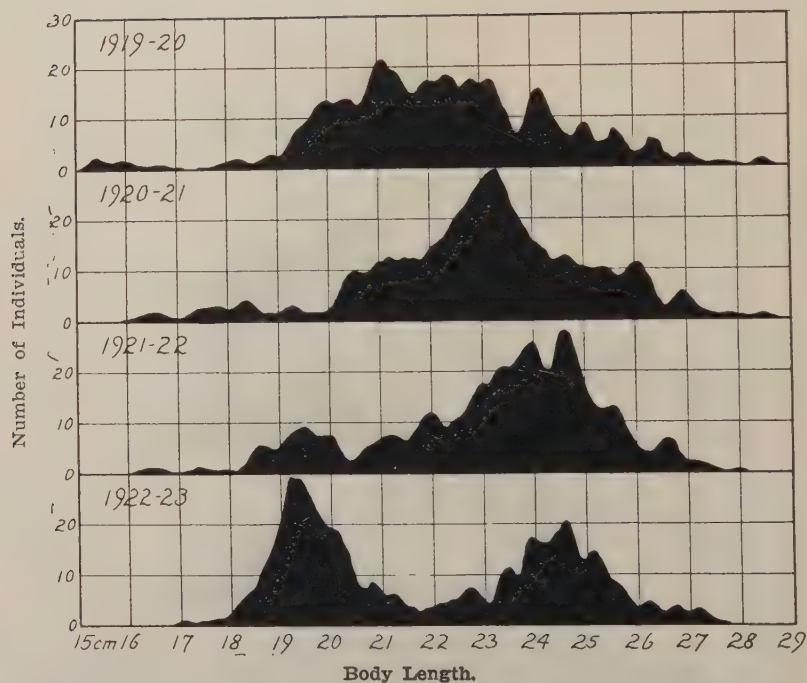


FIGURE 12. Size frequencies of females examined during first lunar period of each commercial season at San Pedro from 1919-20 to 1922-23, expressed as numbers of individuals at each millimeter of body length.

the modes are sharper and also more variable. Figures 11 and 12 show the form of the length-frequency distribution for males and females, respectively, for the first lunar period of the commercial season in the four years studied. Here, as in the whole season curves, two major size-groups may be followed from year to year and their progress noted. Figures 13 and 14 are similar curves showing males and females, respectively for the second lunar period of the same years. The same characteristic size groups, showing the same progress, as in

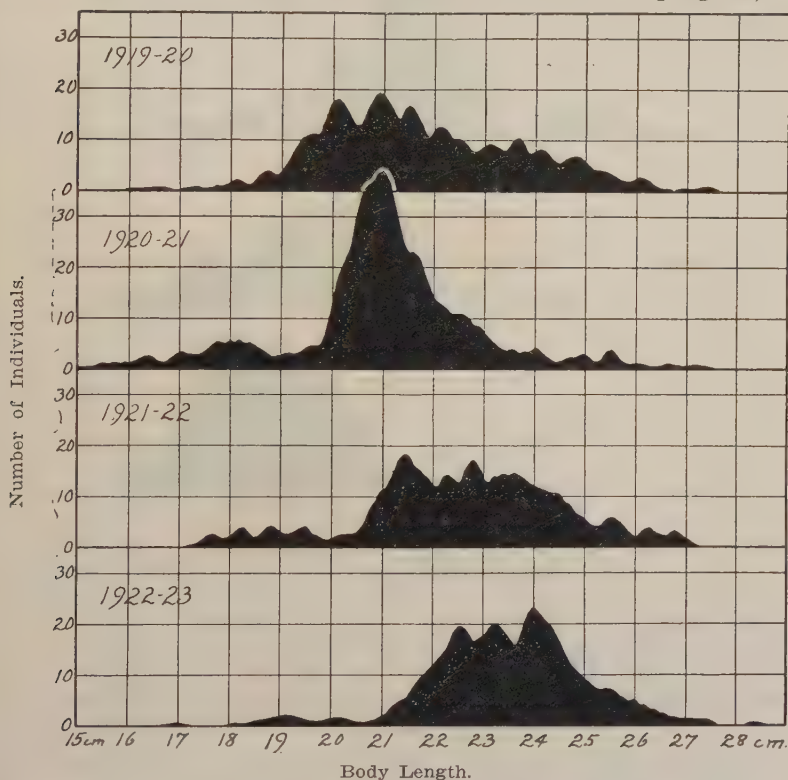


FIGURE 13. Size of males examined during the second lunar period of each commercial season at San Pedro, from 1919-20 to 1922-23, expressed as numbers of individuals at each millimeter of body length. Lunar periods occurred as follows:

- 1919-20—February 4th to March 4th.
- 1920-21—February 22d to March 23d.
- 1921-22—February 12th to March 13th.
- 1922-23—February 1st to March 3d.

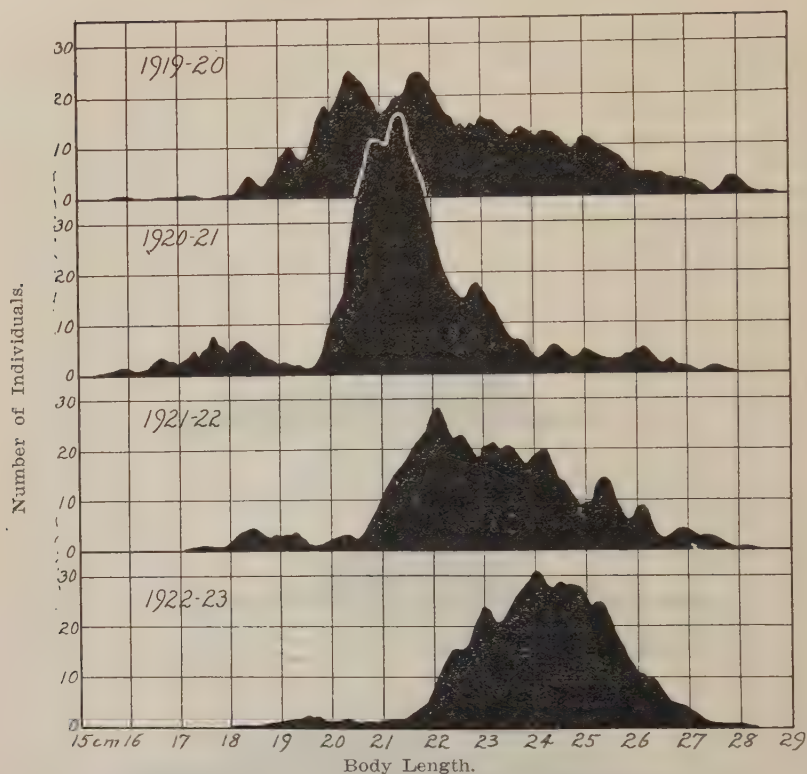


FIGURE 14. Size frequencies of females examined during the second lunar period of each commercial season at San Pedro, from 1919-20 to 1922-23, expressed as numbers of individuals at each millimeter of body length.

the previous curves appear again. The approximate position of the two dominant groups may be summarized in the following table:

Observed Positions of Modes of Dominant Size Groups in Different Years.

	First Dominant Group Season Curve				Second Dominant Group		
	1920	1921	1922	1923	1921	1922	1923
Both Sexes	202	212	220	226	230	234	240
						or 240	or 245
Males	202	209	216	219	227	235	240
				or 226			
Females	203	212	221	226	231	235	240
						or 240	or 245
		First Lunar Period					
Males	202	---	216	---	228	235	241
Females	200	212	220	227	233	240	246
	or 204						
		Second Lunar Period					
Males	201	208	215	226	---	228	240
		or 210				or 236	
Females	204	209	221	230	229	235	240
		or 214				or 242	or 245

Because of the uncertainty of accurately locating the different modes it is difficult to plot satisfactorily the yearly progress of the different groups, but the first dominant group is less variable in position and may therefore be plotted. Figure 15 represents the upward slope of this group in the various years, curve A showing the positions of the first trough, and curve B the positions of the first crest or mode. Here the *fact* of progress in size is clearly shown, but again the *amount* of the increase is doubtful, especially in 1923 when the position of the true mode of the males is difficult to determine. The curve must be therefore interpreted as a qualitative rather than a quantitative determination of the growth of this dominant size-group.

(4) The appearance of a new group in the season of 1922-23 composed of smaller fish than normally present in the commercial catch is apparently due to the arrival at commercial size of a new and

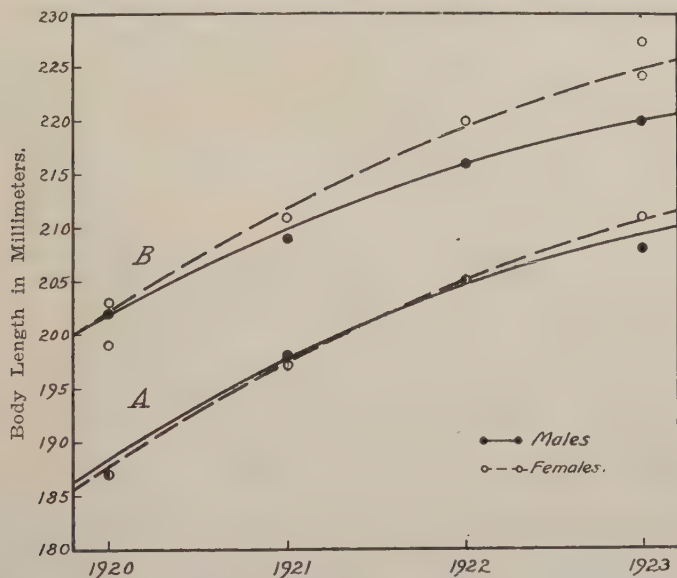


FIGURE 15. Progress of first trough (A) and first mode (B) as their individuals increase in body length. Seasons indicated by year in which data were actually taken, for example season of 1919-20 shown as 1920. Compare figures 9 and 10.

abundant year-class. Fish of this size have appeared in previous years in our length-frequency curves as scattered groups with modes between 180 and 194 mm. They have not been of sufficient abundance, however, until 1922-23 to have much commercial value, although there is good market demand for such sizes. They appeared in that season in such abundance, as shown in figures 7 and 8, that they overshadow completely the next larger age-group and may therefore on the basis of the single season's data be considered as composed chiefly of a dominant year-class.

That this yearly shift in the sizes of sardines at San Pedro is due to the growth of certain dominant year-classes and not to changes in the physical environment may be seen by the regularity of the change year by year for a four-year period, together with the starting again of

the cycle of change by the appearance of a new class of small fish. Had hydrographic or meteorological conditions produced the increase in sizes of fish during 1920-1922, it is inconceivable that these same conditions could have been responsible for the appearance of a run of fish both larger and smaller than those of the preceding year. Obviously the increase in size in part of the run is due to the growth of the previously recognized dominant groups and the run of small fish is due to the first appearance of a new dominant class in the commercial fishery.

The shift of the larger sizes of sardines from month to month during the various commercial seasons, as shown in figure 7, has been noted and commented upon above (p. 137), but we may now consider these changes from the point of view of the shifting importance of dominant size-groups. As has been pointed out, when fish over 20 cm. are considered larger sizes have been present year after year in January or February than in the later

Seasonal Shift of the Dominant Size Groups.

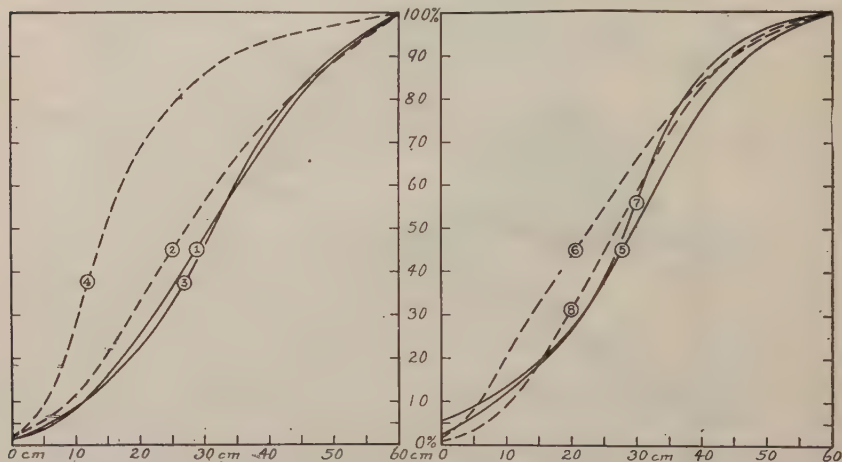


FIGURE 16. Comparison of first and second lunar months of the commercial seasons by means of cumulative frequency curves, representing total number of individuals in each lunar period as 100 per cent.

Solid lines—First lunar months.

Broken lines—Second lunar months.

Nos. 1 and 2—Months of season of 1919-20.

Nos. 3 and 4—Months of season of 1920-21.

Nos. 5 and 6—Months of season of 1921-22.

Nos. 7 and 8—Months of season of 1922-23.

months. In other words, the second dominant size-group has been more numerous in the first lunar period of the commercial season, while in the second lunar period, the ratio is reversed, the first dominant size-group being more numerous.

This condition is shown by the accompanying graph (figure 16) which is a comparison of the length-frequencies of the two dominant size-groups in the first and second lunar periods of the commercial seasons of 1920-1923. In deriving these curves an approximate growth correction is applied by using as the zero-point of the length scale the approximate position of the trough plotted as A in figure 15. Thus all fish smaller than the "first" dominant size-group are eliminated

from consideration. The zero-point in figure 16 corresponds to the following actual lengths: 1920, 185 mm.; 1921, 196 mm.; 1922, 205 mm.; 1923, 210 mm. Then, in order to consider comparable parts of the curves, the 60 mm. section above this zero was taken in each period, and the frequency of every fifth ordinate in the original frequency table was read off. From these frequencies, the percentage frequencies were computed and these when added yielded the data for the cumulative percentage frequency curves shown in the figure. Each point on the curve therefore represents the per cent of all fish in the 60 mm. range (which includes both of the dominant size-groups) which lie below any certain length. In each year, the curve for the second lunar period lies to the left of the first period curve in that section of the length range occupied by the first dominant size-group (about 15 mm.) which indicates, as was said, that the first dominant group runs most abundantly after the larger fish have become more scarce.

Whether this peculiarity of the run is due to the spawning migration of the larger fish which may mature earlier in the season and hence leave the fishing area first, or whether it is a response to changes in the physical environment, can not be said from the present data. It is, however, a noteworthy fact and its recognition may prove of practical value to canners if it is shown by future years to be an invariable habit of the species.

It is the natural tendency of men of affairs to pay but scant attention to the results of "theoretical" or pure science until they have been shown to possess practical or commercial value.

**Practical Importance
of Size Fluctuations
of Sardines in the
Commercial Catch.**

So it has been felt desirable to determine the effect upon the sardine canning industry of the growth of a dominant year-class and the resultant shift in the composition of the commercial catch. What, then, will be the difference in the sardine pack if the fish do average a half inch or so longer in one year than in another?

In answering this question, it is necessary to discover whether it is market demand, or the actual size of the fish which determines the character of the pound-oval pack. Certain markets demand only large fish (four per can), some prefer smaller ones (eight or ten per can), while other markets receive only the intermediate sizes. So it is important to know whether all orders can be filled from fish of uniform size by merely canning a larger or smaller portion of each fish, or if different sizes of fish are required to meet the different demands. If the latter be true, it behooves the canner to foresee an abundance of suitable raw material before developing a market with a particular or restricted demand.

Fortunately, extensive data bear upon this problem. This whole paper thus far has dealt with the records of the commercial catch, and through the courtesy of the several canning companies concerned, we have been able to gather and compile detailed statistics of the commercial pack. It only remains to analyze and compare the two series of records to determine the degree of dependence of the pack upon the character of the catch.

There are several steps in the process of reducing the two systems of data to comparable scales, which may be enumerated as follows:

1. Our records of the catch are based on length measurements; the records of the pack are based upon the number of fish per can. But it was not feasible to establish by direct experiment the actual lengths corresponding to any number.

2. A basis for establishing the relationship between the scale of length and the scale of number-per-can can be found by noting certain outstanding peculiarities in one system which may be reflected in the other.

3. The commercial pack records exist in a form in which these peculiarities can not be directly traced without simplification and analysis.

4. The analysis of the pack yields a record which may be reduced to a length scale and may therefore be compared directly with the records of the catch and the degree of dependence between the two observed.

The simplest method of establishing the relation between length of the fish and the number packed per can might have been to pack a quantity of measured fish in the cannery, but this problem was not foreseen until after the close of the 1923 canning season, and the method at best could have given but faulty results without the most extensive observations. Likewise the cutting of a great number of cans from the pack for length measurements would have been attended by considerable difficulties and the results limited in the same way as in the first method.

There are, however, peculiarities in the records of the season's catch, which, though modified by grouping according to a scale of larger units, are sufficiently distinctive that one may expect them to be reflected in the records of the pack and thus become a basis of comparison between the two systems. By referring again to figure 7 it may be seen that the December run in 1922 consisted of but one size-group of fish with a mode at 192 mm. January, 1923, fish were divided into two distinct groups, one small (mode at 192 mm.) and one large (mode at 240 mm.), February's fish consisted almost entirely of the larger of these two groups, while the fish in March consisted of the smaller group together with another of intermediate size.

With these facts in mind we may turn to the consideration of the records of the commercial pack.

The pack records of the 1922-23 season from a number of firms at San Pedro (whose identity is concealed for obvious reasons) were examined and analyzed. These records, covering a pack of about 350,000 cases, show the daily production of each plant according to the number of fish packed in each can. The size-categories in the records differ in the different canneries and at different times in the season, the more frequent numbers-per-can being 4, 4-5, 5, 5-6, 5-8, 6-7, 8-10, and 10-12. There was no practical way of determining the relative importance of 4's and 5's in such a group as 4-5, so the assumption was made that both sizes were equally abundant. Because of the character of the variations in the data the error introduced is insignificant, and the number of cases of each size-category was therefore distributed equally among the various numbers in each group. In this way values were derived representing (theoretically) the number of cases containing 4, 5, 6, etc., fish per can produced each month of the season by each cannery investigated. These numbers were reduced to per cent of the total month's production in each plant, and all the

plant percentages added together and averaged to obtain the average percentage production in this port according to the number of fish per can. The results of this step are presented in the following table:

Relative Quantities of Sardines Packed in 1923 at San Pedro According to Number of Fish per One-pound Can.

No. fish per can	Dec. '22 per cent	Jan. '23 per cent	Feb. per cent	Mar. per cent
4 -----	---	27.5	28.8	5.4
5 -----	.4	34.5	40.8	7.3
6 -----	2.7	10.3	15.5	21.5
7 -----	9.6	3.3	2.4	22.9
8 -----	18.3	5.1	2.7	10.5
9 -----	22.0	7.4	4.0	12.8
10 -----	26.4	7.2	4.5	15.0
11 -----	13.0	3.3	.7	3.5
12 -----	7.5	1.4	.5	1.2
Totals -----	99.9	100.0	99.9	100.1

The above table of quantities packed may be reduced to relative numbers of fish at each size, by multiplying the numbers of cases by the number of fish per can, and reducing to per cents of the total. The following table gives as a result of this step the *relative number* of fish canned according to the number per can:

Relative Number of Sardines Packed in 1923 at San Pedro According to Number of Fish per One-pound Can.

No. fish per can	Dec. '22 per cent	Jan. '23 per cent	Feb. per cent	Mar. per cent	Season Av. per cent
4 -----	---	18.3	21.1	2.9	10.6
5 -----	.2	28.8	37.4	3.1	17.4
6 -----	1.5	10.3	17.0	17.5	11.6
7 -----	7.3	3.9	3.1	21.8	9.0
8 -----	15.8	6.8	4.0	11.4	9.5
9 -----	21.4	11.1	6.6	15.8	13.7
10 -----	28.5	12.0	8.3	20.4	17.3
11 -----	15.6	6.1	1.4	5.2	7.1
12 -----	9.7	2.8	1.1	2.0	3.9
Totals -----	100.0	100.1	100.0	100.1	100.1

To reduce the scale of number of fish per can in the foregoing table to one of body lengths, it is necessary to determine the actual lengths of fish which are put into a pack 4, 5, 6,—12 per can. It will be remembered that two predominant sizes of sardines were taken during the season, one about 192 mm. and one about 240 mm. in body length. In the above table two similar predominant groups appear, one of fish packing 10 per can and one packing 5 per can. We may assume, for the time being, that the groups in the two series are identical, that fish which pack 10 per can have a modal length of 192 mm., and that fish which pack 5 per can are about 240 mm. long.

The validity of this assumption of size may be tested (1) by observing the shifting importance of the various groups and (2) by determining the position of the intermediate sizes and comparing their length-weight relation with the normal curve for that value. Thus in noting the shift from month to month of the various abundant size-groups as canned, it is apparent that the smaller group packing ten

fish per can is much reduced in importance from December to January and the group of larger fish, five per can, is greatly increased. This shift continues in February when almost the entire pack consists of the larger fish. In March, however, the larger fish are lacking and only the small and intermediate sizes are present. This is exactly what occurs in the catch as shown by the curves of length-frequency (figure 7) and it is therefore justifiable to consider the two prominent modes in the two series of data as actually coincident.

We may also assign lengths to the various intermediate sizes by inspection of the length-frequency curves by matching points of

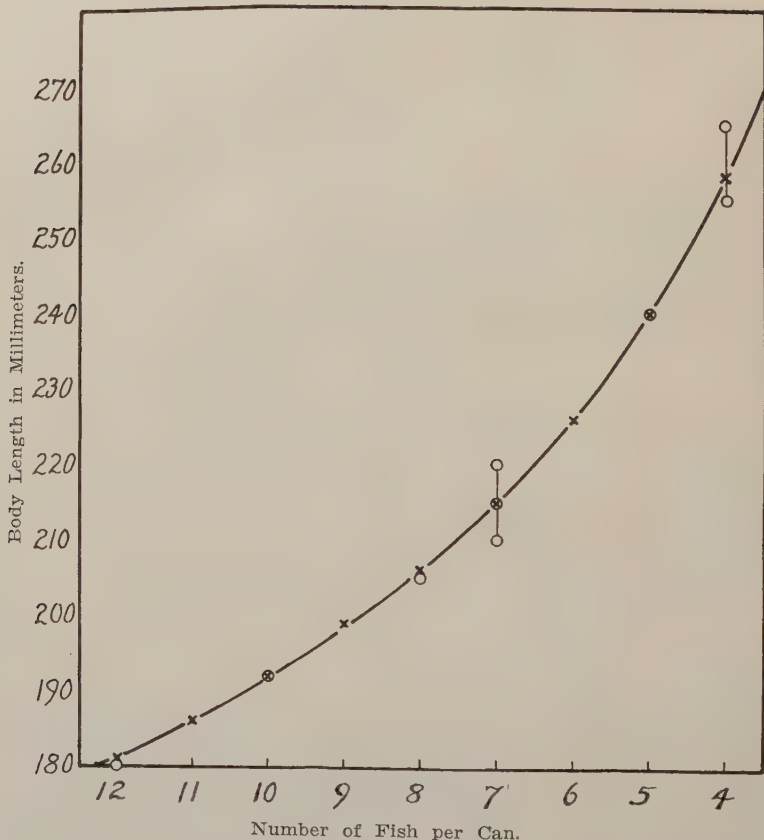


FIGURE 17. Curve showing correspondence between length of body of sardine and number of fish packed per can. See text.

Circles—Observed corresponding modes.
Crosses—Computed lengths.

abundance and lack in the two series of data, that of catch and that of pack. Thus, the relatively lacking fish packing seven per can in January and February may be assigned lengths from 210–220 mm. The length of 7's, abundant in March, must be about 215 mm., and 8's which are scarcer in March must come from fish 205 mm. long. The minimum size, 12 per can, can not be much less than about 180 mm. on the average, and the largest, four per can, can not greatly exceed 255

or 265 mm. in length. When these points are plotted on a graph, as in figure 17, we find that the lengths of the intermediate sizes between 10's and 5's as well as the estimated extreme sizes, lie upon a regular curve and are therefore consistent among themselves.

This method of determining the lengths of fish in the various sizes as canned may be checked by an independent calculation of the lengths from the weights of fish in the can. An arbitrary value of 14 oz. or 397 grams was taken as the weight of fish in a one-pound oval can. (Any other weight could have been used.) Then the average weight of fish canned twelve per can is one-twelfth of 397 gms. or 33.1 gms. The weights of the other sizes are one-eleventh, one-tenth, etc. But, as before observed, the length of fish packing ten per can is 192 mm. and that of 5's is 240 mm. The ratio of these weights to the cubes of the corresponding lengths is not a constant as in the familiar length-weight formula, $L^3 = WK$, but a variable, having a value, as shown in the following table, in the first case of 178,300 and in the second, 174,100. Assuming that the change in this variable is a simple straight line change such as a $\pm bx$, the values for each size may be computed, and from these the length of each size determined according to the formula $L = \sqrt[3]{W(a-bx)}$ in which L equals body length in mm.; W equals average canned weight in grams; a equals 178.3 times 10^3 ; b equals intervals of numbers of fish, with 10 per can being the zero-point; and x equals an increment of 0.84 per interval. These computations are summarized in the following table:

Computed Lengths of Sardines According to Numbers Packed in Can.

I	II	III	IV	V	VI	VII	VIII	IX
No. per can	Inter- val b	Av. can- ned Wt. gms.	Obs'd Lgth. mm.	$\frac{Lgth.^3}{1000}$	$\frac{Lgth.^3}{1000}$ ·001 Wt.	Com- puted factor	Com- puted Lgth. mm.	Com- puted Lgth. mm.
					(V ÷ III)	a-bx	(III x VII) ($\sqrt[3]{VIII}$)	
12	-2	33.1	---	---	---	180.0	5,958	181
11	-1	36.1	---	---	---	179.1	6,466	186
10	0	39.7	192	7,078	178.3	178.3	7,078	192
9	+1	44.1	---	---	---	177.5	7,828	199
8	+2	49.6	---	---	---	176.6	8,760	206
7	+3	56.7	---	---	---	175.8	9,968	215
6	+4	66.2	---	---	---	174.9	11,578	226
5	+5	79.4	240	13,824	174.1	174.1	13,824	240
4	+6	99.3	---	---	---	173.3	17,209	258

Difference or $178.3 - 174.1 = 4.2$ (VII)

$$\text{Difference per interval} = \frac{4.2}{5} = 0.84 = x$$

These values of the computed lengths of fish in the various packs when plotted upon the same graph as the observed modal points (figure 17) lie upon the same curve and thus constitute a check upon the two methods of length determination.

We now have the data in proper form to plot the curve of length-frequencies of the fish in the commercial pack so that it may be compared directly with the curves of length-frequency of the catch as shown by our semiweekly samples. But the frequency record of the catch is expressed in millimeter units and must therefore be grouped

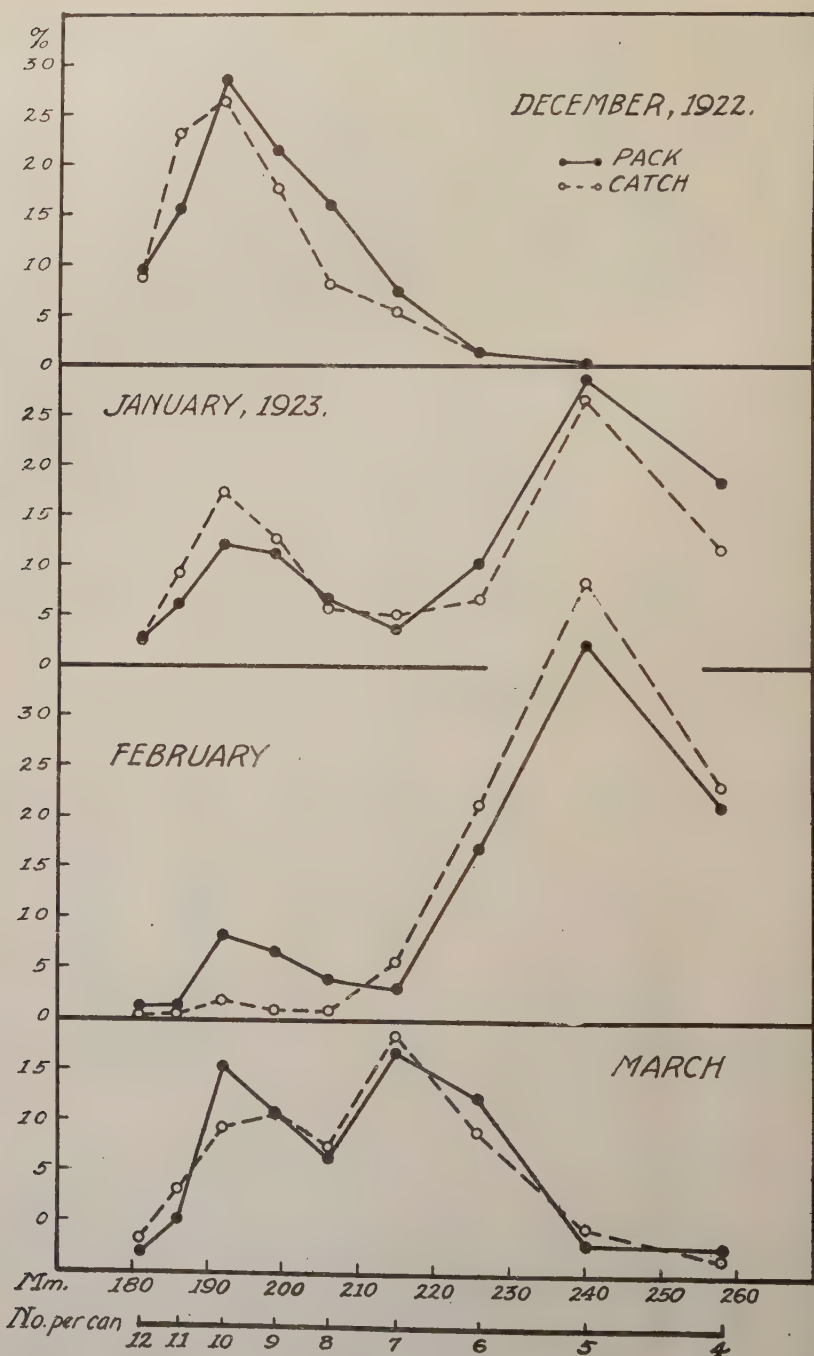


FIGURE 18. Correspondence of actual pack distributed according to number of fish per can and pack calculated from catch, as described in text, according to months of season of 1922-23.

to fit the scale of size according to the number of fish packed per can. The grouped frequency record of the catch is presented in the following table:

Length Frequency of Catch Grouped According to the Number of Fish Packed per Can.

No. per can	Body Lgth. mid pt.	Class limits mm.	Frequency in per cents			
			Dec. '22	Jan. '23	Feb.	Mar.
12	181	179-183	8.71	2.27	.08	3.33
11	186	184-189	23.02	9.28	.50	8.15
10	192	190-195	26.47	17.20	1.09	14.30
9	199	196-202	17.71	12.73	.99	15.27
8	206	203-209	8.31	5.83	.78	12.40
7	215	210-220	5.39	5.19	5.98	23.35
6	226	221-231	1.13	6.70	21.37	14.15
5	240	232-248	.08	26.48	43.61	4.90
4	258	249-267	.00	11.83	23.31	1.92
Above and below this range			8.99	2.48	2.29	2.22
Totals			99.81	99.99	100.00	99.99

When the curve of the length frequencies of the pack and of the catch are plotted on the same graph, as in figure 18, a direct visual comparison may be made between the sizes of fish utilized by the canners and the sizes supplied to them by the fishermen. Because of the approximate character of the data, no measure of correlation was computed, but it is plainly evident that a high degree of positive correlation exists between the size composition of the catch and that of the pack. In other words, during the winter season of 1922-1923 at San Pedro all sizes of fish were canned as received from the fishermen and the resulting product marketed wherever possible.

If the condition limiting selection of sizes packed continues year after year, it can readily be seen what effect upon the sardine pack a small shift in the size composition of the catch would produce. An increase of one centimeter in the length of large fish 240 or 250 mm. long would not appreciably change the character of the pack, but an increase of the same amount in the group of small fish 190 mm. long would change the character of the pack from predominantly 10 and 11 to 8 and 9 fish per can. From the study of the growth of the dominant size-groups, this amount of increase may be expected in the 1922-23 group of sardines having a modal length of 192 mm. By the time of their appearance in the commercial season of 1923-1924, they should have grown to a size which, under present canning practice, will pack at 9 or 8 per one-pound oval can. We may therefore expect the pack of the coming season to include greater quantities of the middle sizes than that of the present year.

These expectations of the character of the pack of the coming season are entirely based upon the continuance of the present cannery practice. The effect of the existence of the dominant size-groups might be entirely masked by increasing the production of fish meal made from fish selected and discarded because of lack of demand for a certain size. Also, concentration of fishing activity in only a part of the regular season might restrict the catch so that only certain groups would be taken. Whatever changes in practice may occur, the entire

canning industry must react in some manner to the growth of the dominant year-classes which determine the actual composition of the sardine stock, and a preknowledge of these changes must prove a valuable asset to the industry.

ERRORS IN METHOD OF SAMPLING USED IN THE STUDY OF THE CALIFORNIA SARDINE

By

WILL F. THOMPSON.

This paper is No. IV of a series published by the Fish and Game Commission in Fish Bulletin No. 11, and is Contribution No. 55 from the California State Fisheries Laboratory. It was submitted for publication virtually in the present form early in 1924.

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ERRORS IN THE METHOD OF SAMPLING USED IN THE STUDY OF THE CALIFORNIA SARDINE.

By WILL F. THOMPSON.

In the preceding paper by Mr. Higgins, and in that by Mr. Scofield, the passage of unusually abundant year-classes, which have been termed dominant year-classes, is demonstrated. The data were collected at San Pedro and Monterey by methods already explained, based in part upon Mr. Sette's critical examination of their adequacy.

These methods, however, form a system of sampling with certain inherent peculiarities. Since the results from our work are naturally extensively influenced by these peculiarities, we do not feel that our investigation can be termed truly scientific until we have analyzed the possibilities and limitations of our methods. This analysis would have been carried out by Mr. Higgins had he remained with the commission. The writer feels that his part of substitute has perhaps been played imperfectly.

There can not be much question but that the commercial catch, upon the understanding of which we have laid so much emphasis, gives incomparably the best means of sampling the population of fish in the ocean. Including as it does many boat catches, it is representative of a considerable area and many schools, and it avoids the extreme chance variability of the single boat catch, which is dependent entirely upon the ability of the fisherman to find a school, and is representative of that school only for the day in question. The commercial catch is comprised of many such boat catches and represents many schools; while any alternative system of sampling must include few catches, and must represent a limited number of schools and restricted areas.

But the advantages of the magnitude of the catch and the abundance of the samples do not eliminate all defects. For a discussion of some of these the reader is referred to the first paper of this series. The present one confines itself to a discussion of the errors which become evident through examination of the data itself and its internal "structure."

Fishing with apparatus limited in scope is highly selective under any conditions and an attempt to narrow and to rigidly define the circumstances under which a catch must be made to be used as a sample by us, at once leads to an inordinate heightening of the selection. This must render the samples nonrepresentative of the very thing we seek to understand, the catch, and also of the abundance in the ocean. It is therefore safe to assume that there are errors inherent in the commercial catch used as a method of sampling, or in any modification of it.

The study of these errors seems to us extremely valuable in connection with an understanding of the phenomenon of dominance. It may very well be that only in cases of extreme abundance of a given year-class as contrasted with adjacent year-classes, would dominance be so marked as to overwhelm or even subordinate the errors of sampling. And we have, naturally enough, no reason as yet to expect such extreme dominance, any more than we have to expect the errors of sampling to be insignificant.

As will be seen, our conclusion is, that actual experience with the errors of sampling will be necessary for understanding and following a dominant year-class, and that the results of this experience may need constant revision and correction.

It is especially worthy of emphasis to our readers that we shall in this section deal with our conception of sampling errors as they are met with in the sardine fishery of the period 1920 to 1923, inclusive, at San Pedro. They may never again be just the same and may never repeat themselves in another locality. But the general theory underlying their occurrence we believe must be of value in considering fisheries anywhere or at any time.

The presence of a great variation in the relative abundance of various year-classes has been demonstrated clearly enough in the samples from San Pedro. There is no other explanation possible for the very

**Demonstration of
the Existence of
Dominance.**

obvious and even progression in size of the group which lies above 190 cm. in 1919, and the gap which follows and progresses with it. The graphs of these frequencies shown as deviations from the average for four years (figures 6 and 7) are very clear as regards this, the gap being the depression "a." These dominant year-classes are apparently at times separated from one another by a sufficient number of years to render them very distinct during their earlier period of growth.

Since the aim of the investigation is an understanding of the catch of sardines and its fluctuations, the influence of these dominant age-groups upon the total size frequencies which represent this catch must be thoroughly understood.

**Dominance and the
Understanding of
the Catch.**

It is very plain that any age-group must inevitably progress in size at a rate characteristic of the species, and that the influence of an unusually abundant, or of a sparsely represented, age-group must be felt at progressively larger sizes as the years pass by. Knowing the rate of growth, it would seem entirely possible to foretell the effect of variations of this sort, and to prophesy the catch as represented by size frequencies during coming years.

The matter is not, from a practical standpoint, nearly so simple and straightforward as it seems. As far as we can see, the normal course of an age-class is distorted greatly by the errors in any method of sampling which we are able to devise, and it would seem, indeed, that the complex puzzle of the movements of the fish is in itself a source of much of the distortion.

Perhaps light would be thrown on the subject were the ages of individuals ascertainable by means of the scales, but unfortunately, repeated trials by myself and assistants have shown the indistinctness of seasonal marks thereon. However, it is probable that the nature of the sampling errors is such as to affect the age-groups as markedly as it does the size-groups.

The immediate query which must be answered is as to the history of a year-class during its progress in size and age, especially as to its numerical relationship to other year-classes. Does it maintain a uniform numerical importance? Without some knowledge of the usual course of events during growth and the manner this course is represented in our samples, it would seem impossible to foretell the

catch, or to define the significance to the catch of the phenomenon of dominance.

We necessarily begin our study by examining those characteristics of a dominant year-class which may be expected to show themselves in the size frequencies available from our samples. That characteristic of an

The Significance of a Mode. age-group first thought of as an index to its presence is the mode, which is due to the greater abundance of certain sizes. In size-frequency graphs such a mode is shown as a hump or peak

in the curve. And as can be seen in the size frequencies of our catch, there are all types of modes, small and large. The more pronounced ones are undoubtedly more reliable, and the smaller ones less so, but a serious question arises as to where the line between significance and lack of significance lies.

As is well known, with increasing age and decreased growth rate, the older year-classes are overtaken by the younger until, for all practical purposes, the very oldest age-groups coincide with each other in average size and distribution. The modes do, therefore, approach each other and become less distinct as the groups overlap to an increasing amount. The modes of fortuitous origin do not, of course, undergo this change.

It seems to us that the modes of fortuitous origin may very possibly be more pronounced than those indicating year-classes, especially among the larger sizes. Mr. Sette has, in his section, thrown some light upon this phase of the subject, his comparison of systems of sampling having shown that the frequency of the sampling affects very markedly the position and numerical importance of the modes as they would actually occur in the catch sampled. But however extensive the sampling as far as individuals are concerned, there is still left abundant opportunity for the origin of "chance" modes of another type than those due to the variability of individuals.

The individual is not the sole unit of variation. Catches of a certain type, or "runs" having certain characteristics, prevail for varying periods of time, and each of these periods is a variable unit in itself. Their importance must be left unchanged by any increase in number or size of the samples. These periods are undoubtedly variable in their characteristics, such as range of sizes included, average size, and duration. Therefore no theoretical method of calculating the probable error of a given ordinate seems available, because its height does not depend upon the "chance" occurrence of individuals, but rather upon the "chance" occurrence of groups of varying size due to these "runs" or "catches." The small number of groups entering into the value of any given ordinate renders the error due to "chance" very large and there must be abundant opportunity for the selective emphasis of other sizes than those at the age modes. Under a regime of purely random sampling of individuals there can not be much doubt but that the numbers used would prove sufficient to eliminate chance modes, as Mr. Sette has shown, but since this random sampling does not prevail as far as the runs during these periods are concerned, there is, in the present condition of our knowledge, no test for the significance of a mode save that implied in its being a part of a system varying definitely from year to year, in a way to become obvious when successive year catches are compared and such as to render the several modes recognizable as

significant of persistently recurrent groups. This implies the serious consideration of all marked variations until their consistency or lack of consistency can be demonstrated. In its essence, this observation of the catch over a period of years is simply a method of overcoming the time element which enters into the characteristics of these "runs" forming the disturbing groups. Only by increasing the period of obser-

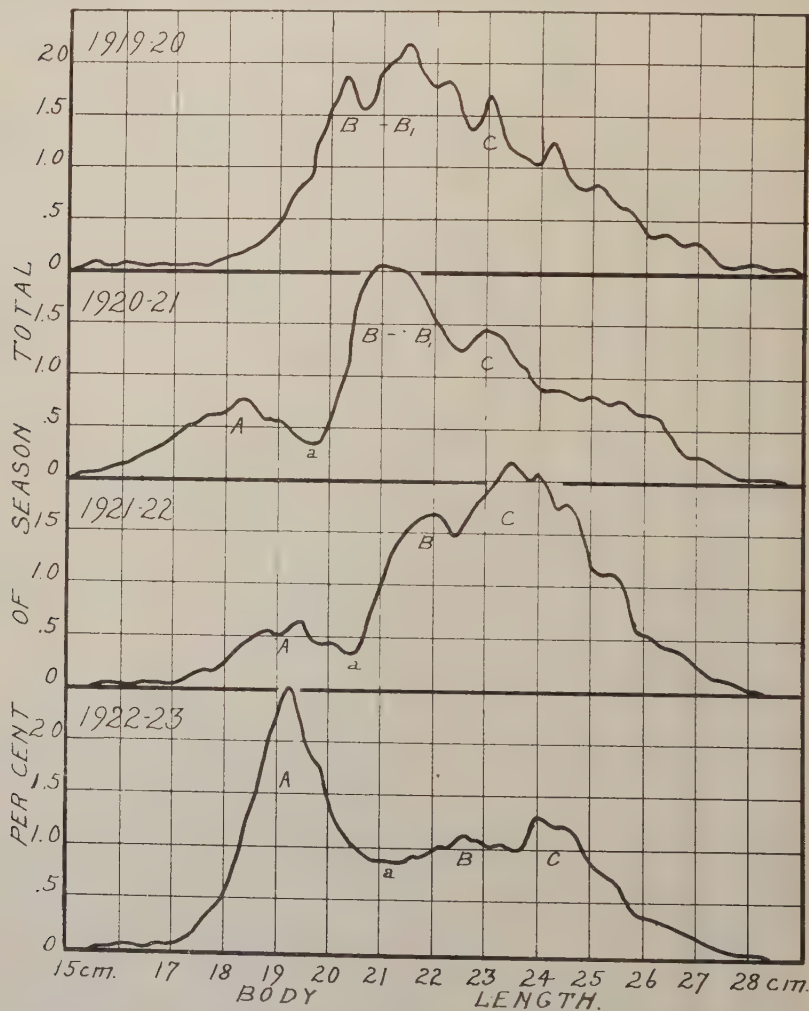


FIGURE 1. Size frequencies for individuals of both sexes examined during each commercial season at San Pedro from 1919-20 to 1922-23, expressed for each millimeter as per cents of the total number of individuals examined each season. After Higgins' mss. Modes lettered as explained in text.

vation can sufficient numbers of "runs" be included to provide a basis for the discounting of the modes they cause.

The attempt to follow modes through from season to season has been only partially successful, as Mr. Higgins and Mr. Scofield have shown for San Pedro and Monterey. Utilizing for this purpose the frequen-

cies for the separated sexes ignores such serious discrepancies between the male and female frequencies for the individual years as, for example, are obvious in the data for 1919-1920, as shown in figures 10 and 11 of Mr. Higgins' paper. Throwing the sexes together as in his figure 9 ignores the growth differences due to sex but, by doubling the number of individuals, makes probable the elimination of chance variations, and this procedure does actually seem to render more apparent the homology of that series of modes which begins at 202 mm. in 1919-20 and ends at 226 mm. in 1922-23. The same is true of the series which is at 230 mm. in 1920-21, at 235 in 1921-22, and at 240 mm. in 1922-23. But the position of the modes in 1919-20 does not agree with this latter series at all. (For the purposes of this paper we have utilized figure 9 of Mr. Higgins' paper to make our figure 1.)

There is nothing in either the form of the individual modes or their rate of progression which throws any light upon the number of age-groups which may be contained within any one of them, although were

One or Several Ages to a Mode.

the modes considered to include those of the smaller sizes, where the groups are plainly annual in origin, this would not be true. It may be easily

ascertained experimentally by anyone that two size frequency curves, each approaching the form of that of a normal distribution of error, may be combined to make one curve not very far from symmetrical and seemingly a unit. A very simple demonstration of this may be made by combining the successive curves in figure 1, in pairs, 1919-20 with 1920-21, 1920-21 with 1921-22, and 1921-22 with 1922-23. Figure 2 results. If the modes in figure 1' indicate year-groups, then in each of the significant modes of the frequencies resulting from the combination (figure 2) it is a known fact that at least two year-group modes are included, yet from the resultant curves it would be exceedingly difficult to prove that fact, or to separate them. The same demonstration may be made by combining the closely adjacent modes of the two sexes, the resultant size frequencies showing single modes. It is therefore hard indeed to determine whether one or two year-classes are contained in each size mode of figure 1, or, to go farther yet, whether the modes in Higgins' figures 10 and 11 are each indicative of a single year-class. The group near 210 mm. in the graph for 1920-21 of his figure 11 is seemingly bimodal, as is indeed that at 195 mm. in the graph for 1922-23 in the same figure. We must therefore admit at once our ignorance as to the actual age composition of the groups upon which our attention becomes focused in the course of this work, and the term group mode will be preferred to that of year-class mode.

Nevertheless, be the composition of these groups what it may, the *rate of progression* shown, should be the mean of the actual rates of growth of the contained year-classes, in so far as our knowledge at present reaches. And the distinctness of such a group—its individuality—should be fully equal, or superior to that of a single age, despite the lessened difference between the average sizes of successive year-groups as age increases and the rate of growth declines. There is, indeed, no demonstrable reason why it should be necessary to deal with individual age-groups. A period of unusually successful years might give rise to an unusually coherent, strongly marked group, and the differences in behavior of this group and one originating in a single

year can not be great, or of a nature to confuse our endeavor to follow size-groups.

It must be remembered, in this connection, that however fundamental the division into year-classes is, from a general biological viewpoint, the chief significance to our present purpose is simply the distinctness and persistence of the group of sizes it forms. When this distinctness vanishes, or the relative numerical status of the year- or group-class ceases to make any significant change in the size frequencies which represent the catch, then its importance as a unit vanishes. So far as we

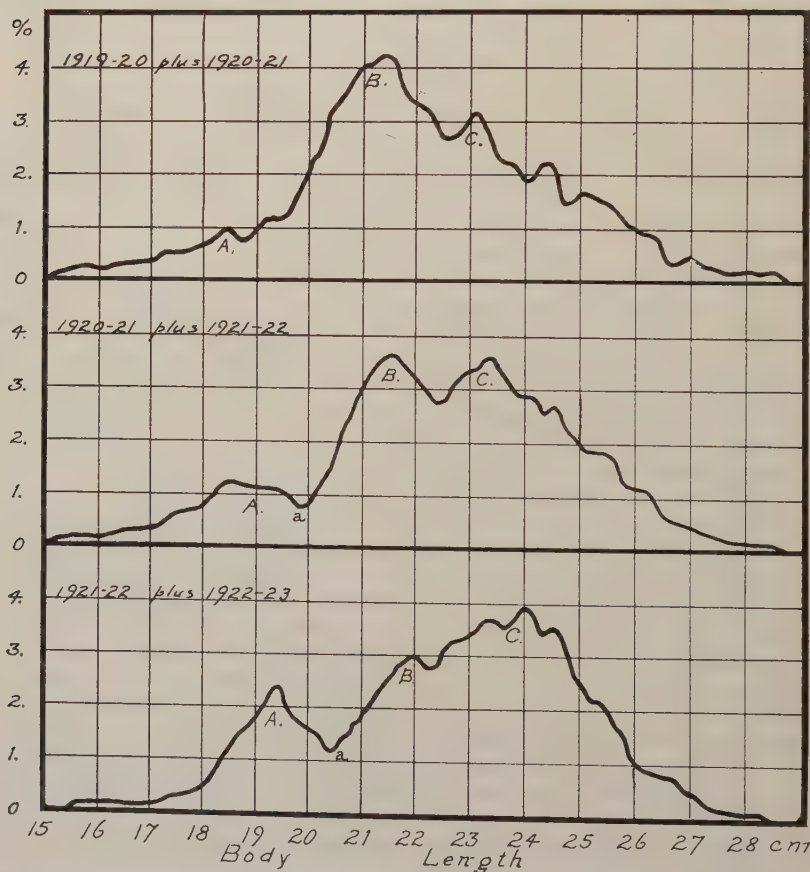


FIGURE 2. Size frequencies of seasons shown in figure 1, combined in pairs by summing percentage values of ordinates at identical lengths. To show principal modes and movement.

can see at present the year-class need not be recognized save as it constitutes a distinguishable group of sizes. We are of the opinion that the determination of age would so limit the numbers handled, because of the labor involved, that our comparison of the numerical importance of the dominant groups would be seriously affected, and with it any hope of accurately following the catch. The determination of the ages of individuals cannot displace our system of measuring great

numbers of individuals, however useful in providing explanations of what occurs.

One might expect either a single dominant age-group, or a fused group of them, to progress steadily according to the rate of growth; and, if it is clearly set off by the lacking groups on each side, to be readily followed at all stages of its progress. The rate of growth should be determinable from this progress, until the various ages of mature fish differ so little in size as to fuse the progressive group with other modes or to make them less than those modes due to chance. Upon the validity of this reasoning depends much of the possibility of foretelling the catch.

It is well worth while, however, to scrutinize this theoretically correct conclusion very closely. This will bring us to a consideration of phenomena of sampling, which may seriously alter any conclusions regarding the effect which these so-called "dominant year-classes" have upon the frequency of various sizes, and upon the rates of growth shown by the modes.

It is the writer's belief that the foundation upon which a practical use of these studies depends in prophesying changes in the run of fish is the fact that a particular group of sizes retains its dominance, or lack, from year to year. If, however, figure 2,

The Persistence of Dominance.

showing the various seasonal size frequencies combined in pairs, is studied, it will at once be seen that the group mode beginning at about 212 mm. in 1920-1921 steadily diminishes in relative importance, while the group beginning at 230 mm. in 1920-1921 as steadily increases. The groups shift position, so far as relative numbers are concerned.

Upon looking at figure 1 again, this peculiar phenomenon may perhaps be distinguished, although not so clearly. To aid examination the modes have been lettered, B and B₁, representing an area with at least two modes and C-C₁, a similar one. It is very possible to question this interpretation of the modes and to deny their homologies as thus adopted. Indeed, the mode shown at 210 mm. in 1920-21 may be regarded as belonging to the same year-class which produced the mode at 240 in 1922-23. Such an assumption would double the growth rate, which would in this case largely exceed the growth rate shown by the defective group of sizes lettered as "a." This would be particularly true when 1920-21 and 1921-22 are compared.

The comparison of the seasons of 1920-21 and 1921-22 brings these problems of interpretation to a focus. The growth rate of the depression "a," presumably caused by missing year-classes, will agree with the growth rate of modes B and C, as shown, but not if the group B in 1920-21 is regarded as the same year-group as C of 1921-22. Yet the shift in predominance in numbers from B in 1920-21 to C in 1921-22 seemingly does not agree at all with what might be expected from the simple theory of the dominant year-classes as developed by the Norwegians, unless B and C represent the same age-class.

If the homologies of the modes as shown by the letters in figures 1 and 2 are correct, it appears as though B and C each were passing through an independent change, not acting together in the expected way. Each group is acting as a separate category of sizes, within which independent changes occur.

What these changes might be must be a matter of some importance in the understanding of the effect of dominant year-classes. Are the year-classes actually varying in relative abundance, or is the effect explainable otherwise?

To answer this question it will be very useful to understand something as to the behavior of the modes under selection. For this purpose the material is very sparse, but worthy of investigation. It should be borne in mind that these modes have been shown to represent truly the catch as we must define it. (Sette.)

That selection limits the lower sizes taken may be assumed, as there must be present great numbers of small sized fish which never appear in the catch. In 1922-1923 an abundant size-group shows itself entering the range of sizes utilized, and the male and female modes of this group have been contrasted in figure 3 taken from figures 10 and 11

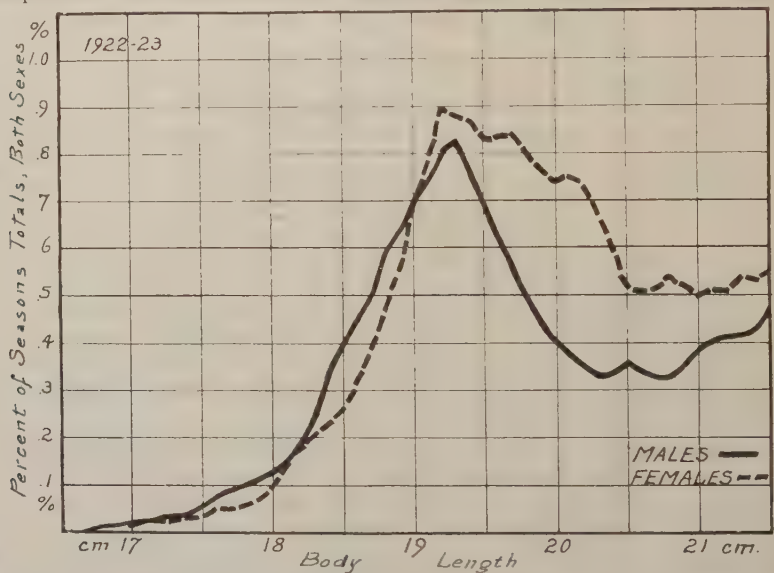


FIGURE 3. Size frequencies of incoming male and female year classes of 1922-23, shown as percentages of total for both sexes for season. To illustrate superimposed left slope and modes. Adapted from Higgins' mss., figures 10 and 11.

of Mr. Higgins' paper. The numbers entering into these curves should render them fairly reliable. But despite the greater average size of the females, the modes of the two groups are the same, and it is that group (female)—which supposedly has entered furthest into the range of sizes taken—which shows the least symmetry and has the greatest dispersion. Presumably this lack of harmony between mode and average size is due to the effect of selection limiting the lower size. We might conclude therefrom that under conditions of active selection for size, the modes of two groups differing in sex do not reflect the real sexual difference in growth, and that the symmetry and range are altered.

It can not be as certain that selection for maturity, or for migration, when it affects the group, its symmetry or dispersion, will be strictly

according to size, rather than age; yet it may be safely assumed that where such selection acts upon age-classes rather than upon size-classes, the general effect upon the size frequencies will be similar to selection by size alone, since age is correlated with size.

It is, however, a very real question as to what section or part of the total year's catch is affected by selection or elimination of smaller sizes. At certain periods in each year there may be a very much higher lower limit than at other times, whether such a selective limit be the result of methods, of migrations or of other influences, and it is accordingly difficult to say at what size selection has acted to disturb the mode or average of a group. Selection of some kind must occur when for a number of days very large fish prevail to the exclusion

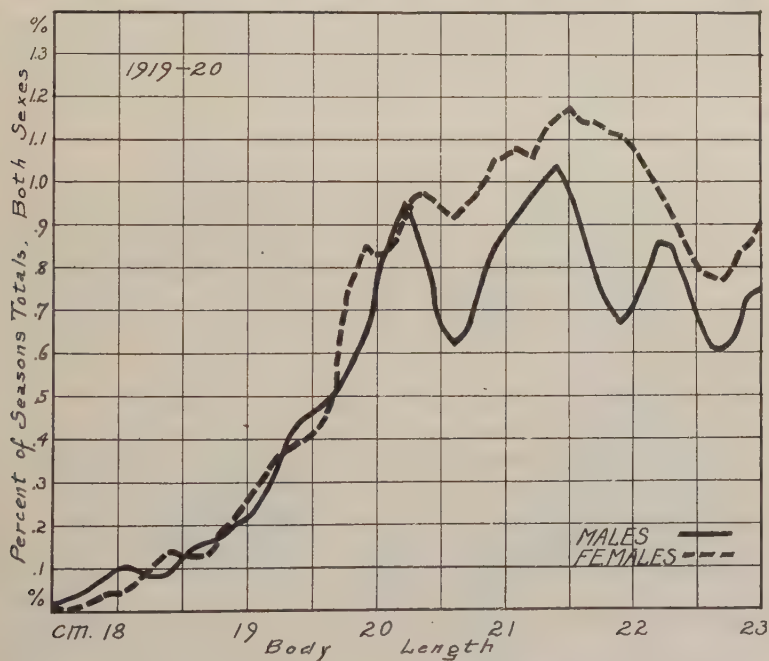


FIGURE 4. Size frequencies of youngest group in 1919-20, male and female year-classes, shown as percentages of total for both sexes for season. To illustrate superimposed left slope and position of modes. Adapted from figures 10 and 11, Higgins' mss.

of smaller and medium sizes, and as yet there is no ground for regarding this selection as any different in character and effect from that which limits the lowest size of the whole season. Among these larger sizes, due to diminished annual growth movement, the groups are not so distinctly separated as among the smaller sizes and the effect of selection upon the groups may not be so easily detected.

Pursuing our comparison of the sexes, we show the first groups in 1919-20 in figure 4, for comparison with those of smaller size shown in figure 3. It is plain that the male and female modes differ radically, and that the female groups are more widely dispersed. The minor modes in the female curve are seemingly chance in origin and impossible to definitely homologize with those of the male curve. If the

disparity in dispersion and distinctness of mode are evidences of selective influences, then both of the groups—of which the male modes give the clearest evidence—have been subject to selection, limiting the smaller sizes first at one level, then at another, and displacing the modes. This is an effect very similar to what we have already observed in the entering class of the 1923 data (figure 3).

From this standpoint a comparison of the males and females for the two seasons of 1920–21 and 1921–22 is interesting. Despite the greater growth rate of the females, as assumed from the position of the modes and the mean sizes, the first marked depression is nearly identical for the two sexes, as shown in Higgins' figure 16—just as the left hand slopes (smaller sizes) shown in figures 3 and 4 correspond in the two sexes.

But the more prominent modes are not identically placed, as they were in the isolated group of the season of 1922–23 (figure 3). They seem, in some degree at least, either to reflect the general displacement toward the larger sizes which the mass of females displays or to be represented very unequally in the two sexes.

It would seem probable that the selective limit, if it exists and is variable, must play back and forth over the middle sizes, with the ultimate result of giving to each intermediate size-group an approximation to a normal distribution, lending a certain validity to the modes. We may, then, expect the modes at the smaller sizes to show especially variable characters, and we must, at all times, look at the modes at any length as possibly questionable except in so far as they represent large divisions of groups of sizes, and save as they show consistency in behavior from year to year.

It must therefore be understood that the attempt to analyze the passage of modes further than the point at which the groups they represent first lose their distinctness, is approached with considerable misgiving. The fact that the modes may be significant must be borne in mind, at the same time that their uncertainty is realized.

For the sake of a clearer analysis of these modes the first section of the season's male and female frequency curves have been cut off figures 10 and 11 of Mr. Higgins' paper. The line of division chosen is one roughly parallel with that described by the area "a" or by mode B, in its growth. The males and females are shown separately in figure 5.

Referring to figure 5, and regarding the males first, the groups marked B and B₁ may be followed. In 1919–20 B₁ is slightly greater in numbers than B. In 1920–21 B₁ has disappeared, or nearly so. In 1921–22 B₁ is not in evidence, and B is much reduced. In 1922–23 neither B nor B₁ is well marked by modes, but they may possibly have resumed their numerical relationship to each other. There can not be much doubt as to the homology of the depression "a" in the frequency curves, nor of the mode B. And for our purposes we may, indeed, simply assume B₁ to be the sizes exceeding those of group B by approximately a centimeter. There is no logical necessity for a recognition of a mode B₁ in each case, in so far as following this sequence of events is concerned. The size frequencies in that vicinity may be compared with B without reference to a distinct mode.

The same comparison may be carried out with the females of figure 5, as taken from figure 11 (Higgins). B₁ exceeds B in 1919–20 and is

less or lacking in 1920-21. B_1 is lacking and B is barely visible in 1921-22. But in 1922-23 the expected relationship fails—perhaps through defects in sampling. The sequence of events is, however, very probably the increase in importance and then the successive dis-

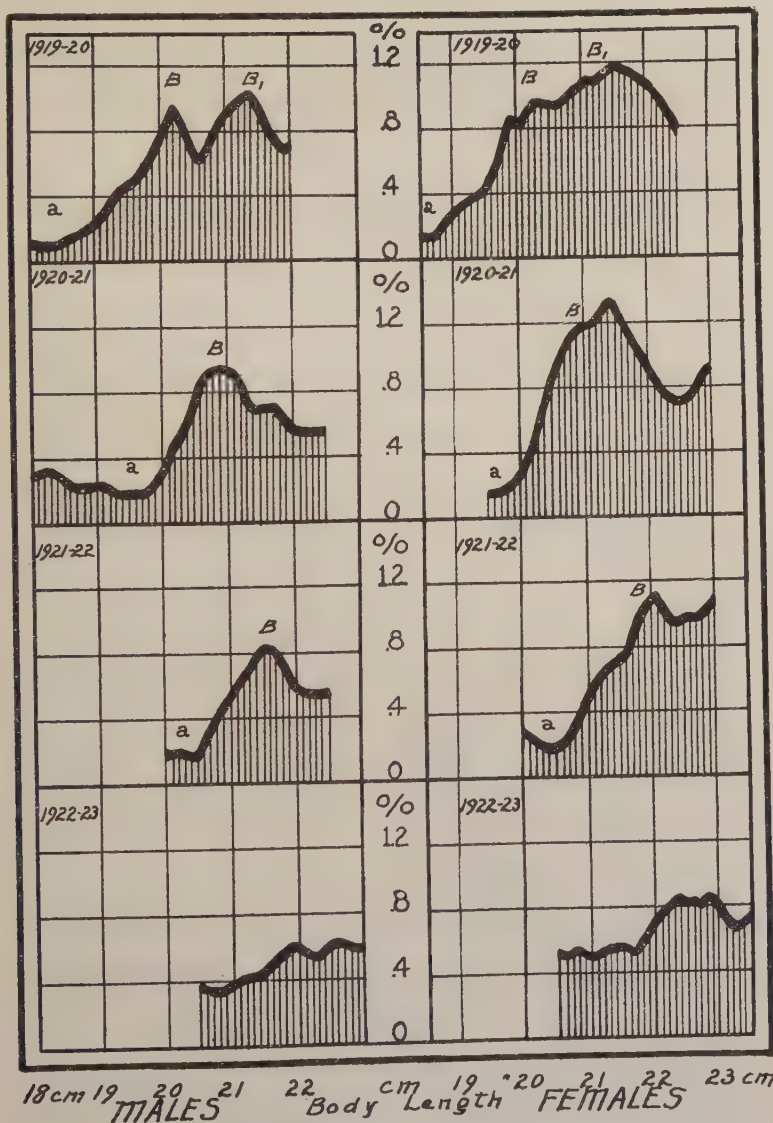


FIGURE 5. Size frequencies for males and females comprising trough "a" and modes B and B_1 , shown as percentages of total of both sexes for each season.

appearance of the older modes as they approach 225 mm., in conformity with what is shown in figure 5.

This tracing of individual modes becomes, in the case of C, rather difficult and subject to question. See figures 1 and 2. Beyond C,

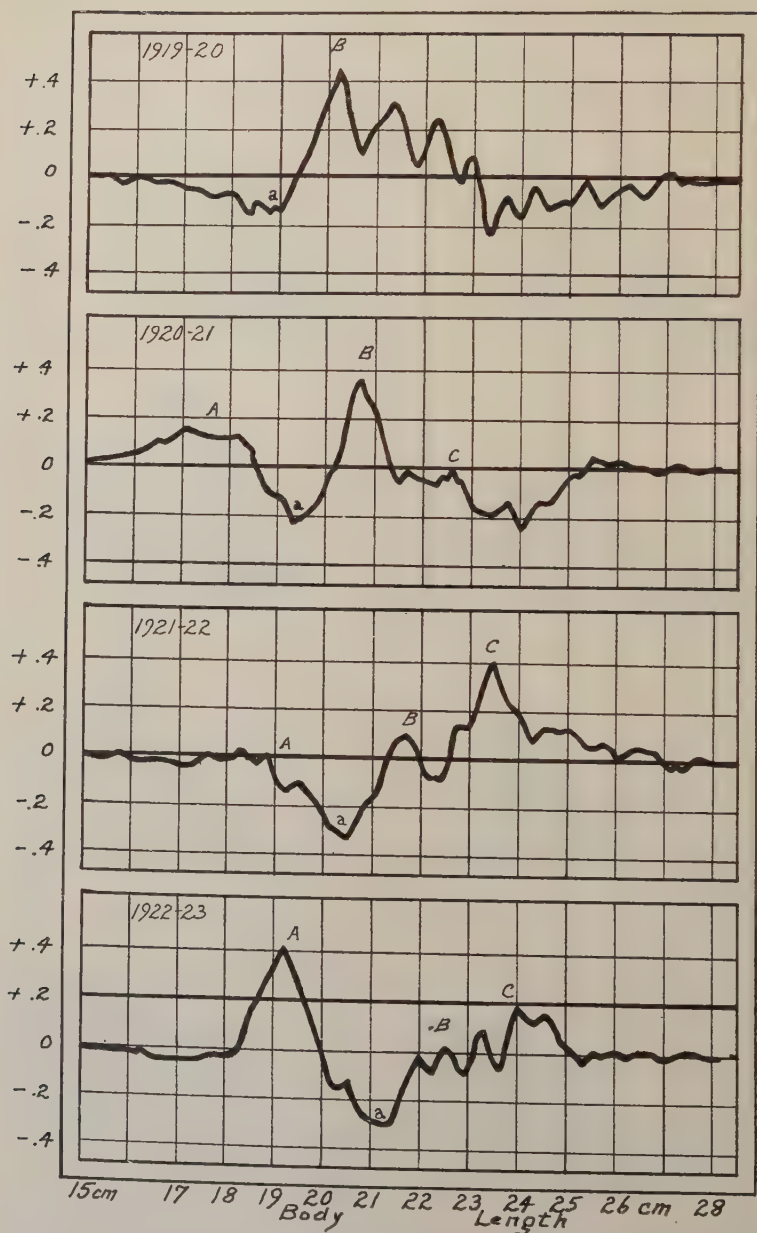


FIGURE 6. Deviation of size frequencies from average ordination for the four years, of males examined by Higgins at San Pedro and shown in his figure 10, as expressed in percentages of the total number of individuals examined each season. Prominent modes lettered A, B and C.

and the area depressed by the character of the sample distribution, it would seem from the available curves impossible to follow individual modes. The behavior of the large groups of sizes alone may be followed safely. In figure 2, in which perhaps the larger mode (C) beyond 22 cm. may be trusted, save as it is displaced by selective influences, both sexes are combined, but each graph represents the data gathered during two years, therefore four times the number of individuals which enter into each graph of Mr. Higgins' figures 10 and 11. This mode (C) shows, however, very little growth when the first and second graphs are compared, and considerably more when the second and third are compared. It shows very clearly an increase in relative importance. In graphs based upon great numbers of individuals, this would seem a rather serious error in the rate of growth, which should decrease from year to year. Furthermore, the considerable increase in relative importance of this mode needs explanation.

The explanation which may most readily be advanced is that the groups immediately below 225 mm. are undergoing, as they grow, *a successive reduction in relative abundance through neglect by selective influences, while the reverse is the case above 225 mm.*

Their modes are plainly untrustworthy and their positions may be distorted, possibly by the same type of selection which changed the incoming groups at 190 mm. in 1922-23.

It appears in this connection that the ability to determine the age of the individual might facilitate the identification of particular series of modes and aid in understanding more quickly the course of a given year-class. It is to be hoped that future work upon the scales or otoliths will provide such a means. We have had no success as yet, and are doubtful as to the feasibility of determining a sufficient percentage of individuals to render the modes at all trustworthy, displaced as they very probably are by selection and by the fusion of adjacent ages. We see no reason why selection should not as markedly displace the average size in a given age group.

The impression of relative independence of the groups above and below 225 mm. is strengthened when it is seen that there is a persistent depression between 22 and 23 cm. in figure 2, and a hint of the same in figure 1 and in figures 10 and 11 of Higgins.

Indications of Division.

It seems to be at a slightly lesser length, 222 mm. and not so clear, in the males of figure 10. As mode B approaches this line of division, or depression, the mode diminishes in importance, and as C removes therefrom, it increases.

In considering this line of division and its persistence, we quite logically come to this question: Is such a depression a consistently present characteristic of the catch?

In answering it has seemed to us that, were this a simple neglect of certain sizes, which would amount to the reduction of their frequencies by a certain percentage each year, the dominant year-class would be nearly as obvious in its passage among these sizes as among any others, *especially in case the variations from the average frequency of each size were considered*, as in figures 6 and 7.

To arrive at any safe conclusion regarding the average catch, or to have a curve of size frequencies representing the "normal" catch for comparison, it would be necessary to have and combine data for a

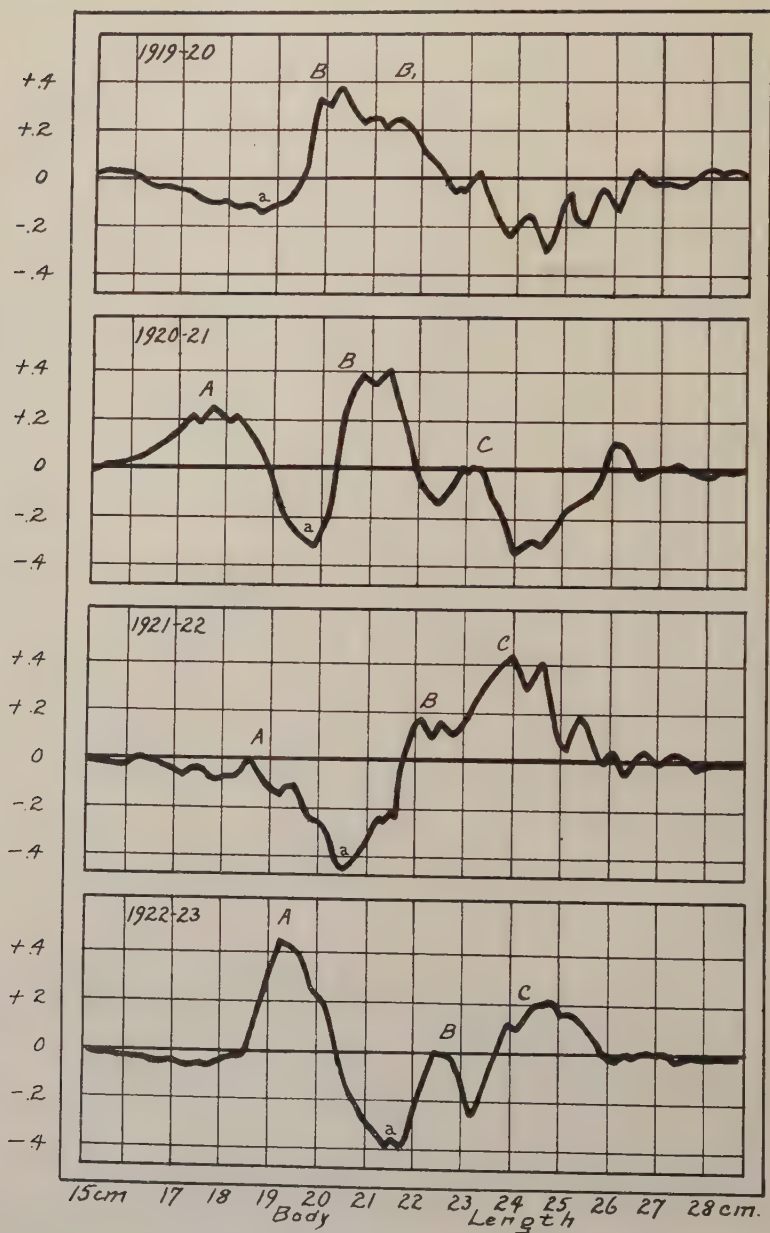


FIGURE 7. Deviation of size frequencies from average ordinates for the four years, of females shown in figure 11 of Higgins' mss., expressed as percentages of the total number of individuals examined each season. Prominent modes lettered A, B and C.

good many years. Were such obtainable, the curve obtained by their summation would be freed from the influence of the dominant year-class fluctuations by the simple expedient of including many stages of their progress in size. Our data, covering but four years, are palpably insufficient. In figure 8 the summation of these four years is shown, the individual ordinates for the four years being summed and divided by four. It is a much more regular type of curve than that for the separate years, despite the sparse data, perhaps because the gaps between dominant year-classes contain less than four missing year-groups. The depression at 226 mm. is present, and must indicate a marked lack of fish at that size if the complete curve should be anywhere near a normal size distribution. But the curve would seem to resemble very strongly a compound one, built up of three or more.

The variations of the successive years' catches from this curve are

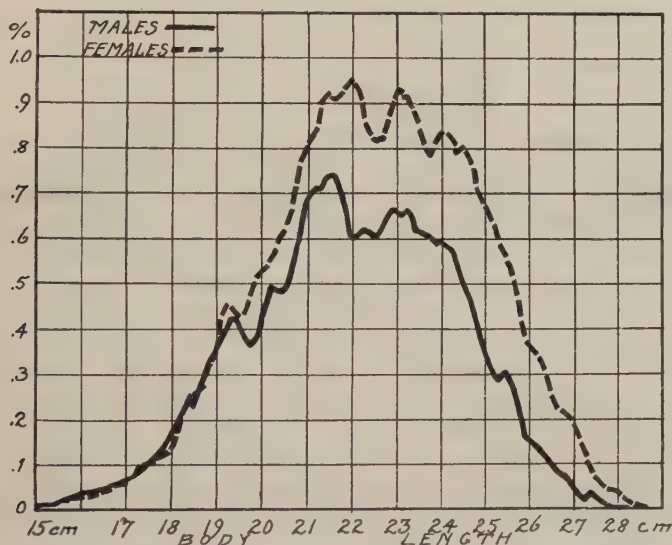


FIGURE 8. Sum of size frequencies of individuals of each sex examined during each commercial season at San Pedro from 1919-20 to 1922-23, as expressed in per cents of the total number of individuals examined each season. From data collected by Higgins, and shown in his figures 10 and 11.

shown in figures 6 and 7. The passage of the area "a" through the graphs is somewhat more clearly shown than in the frequency curves, as in B-B₁. The same disappearance of B and increase of C is evident as in the untreated curves.

From these deviation curves may be gleaned another interesting fact which lends support to the observations already made as to the homologies of the series of B's and of C's, and as to their behavior.

Little Variation in Frequency at Point of Division.

If the area within which the depression was found in the size frequencies, is examined, it will be found that the average deviation from the mean ordinate height for the four years is markedly less than in other sections. (Compare figure 1.) To illustrate this graphically the four deviation curves in

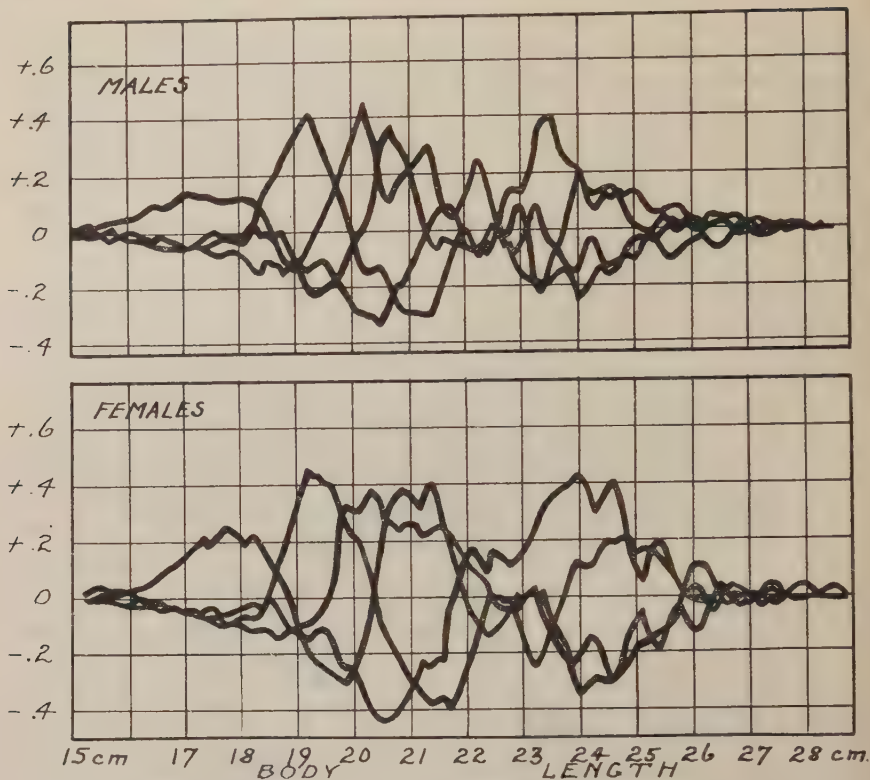


FIGURE 9. Graphs of figures 6 and 7 superimposed. Deviations of size frequencies (expressed as percentages of season's totals) from the average for the four years of sample collection at San Pedro.

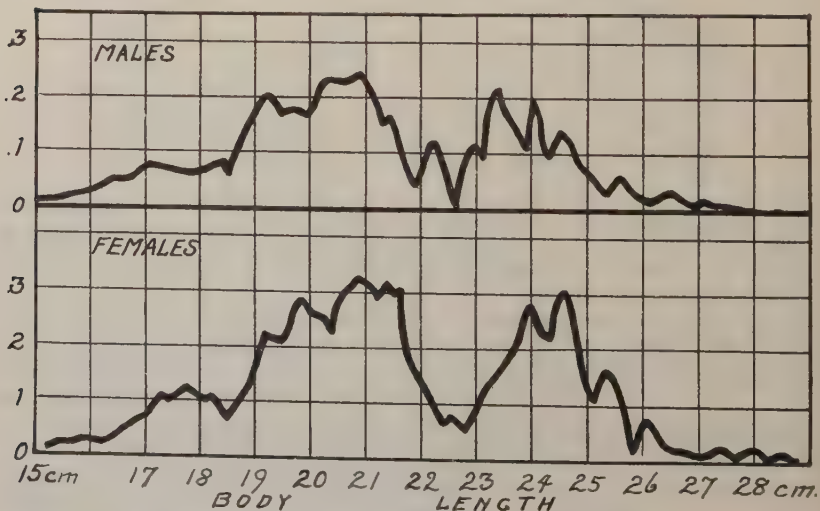


FIGURE 10. Mean deviations, regardless of signs, of size frequencies (expressed as percentages of season's totals) from the average of the four years of sample collections at San Pedro. Same data used as for figures 6, 7 and 9.

each of the figures 6 and 7 are superimposed, to make the graphs in figure 9. As these lines represent the deviations of each year's size frequencies from the average ordinates for the four years, it is plainly shown that at 226 mm. or thereabouts, the catch, as shown by our sampling, *has been remarkably stable*. The dominant year-classes have not affected it, despite the fact that dominance has passed from one side of it to the other.

Such stability is more plainly shown by calculating the average deviation at each ordinate, disregarding signs. The resultant graphs are shown in figure 10. The least variation in height of ordinate evidently falls at between 220 mm. and 227 mm. in the males and between 224 mm. and 230 mm. in the females. For the combined sexes, it falls at 226 mm.

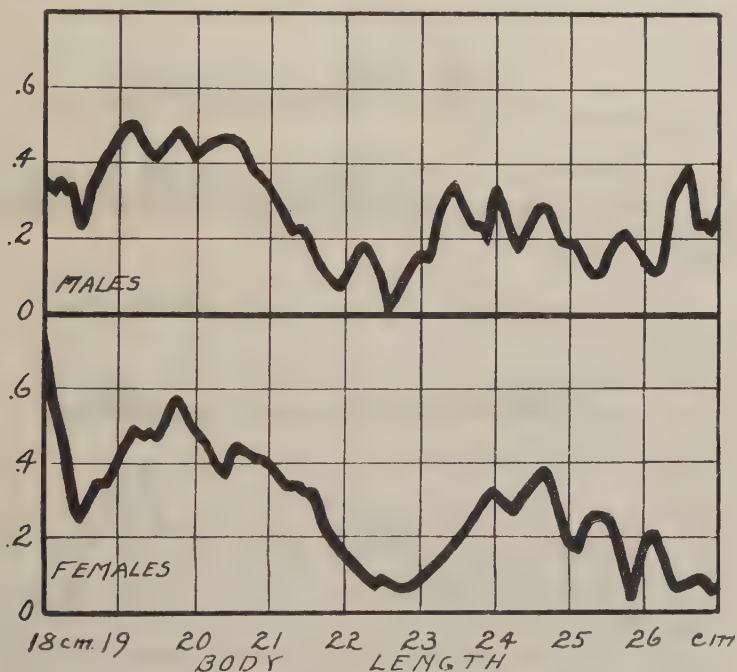


FIGURE 11. Mean deviation, regardless of signs, of size frequencies (calculated percentages of season's totals) from the average of four years sample collections at San Pedro. Expressed as deviations divided by the average in the case of each ordinate. Same data as in figure 10.

The average deviations have also been plotted as per cents of their respective average ordinate heights in figure 11.

We are, it would seem, dealing with a division of the data into at least two major groups, which are characterized by a certain independence. It will be necessary to analyze our system of sampling to grasp the possible explanations of this division.

Distribution of the Samples.

It must be realized at once that the conditions of sampling are not simple, nor are they capable of analysis on a theoretical basis of probabilities. If any one size is selected more fre-

quently, the periods of time during which it is selected do not occur in a random fashion; nor, in fact, in any as yet accurately definable way. If there are groups differing physiologically or morphologically we can not as yet differentiate them. It is possible, however, to show that this lack in the frequencies of sizes of individuals between 22 and 23 cm. is a reality and a reflection of conditions which affect more markedly the distribution of the samples taken than that of the individuals, and to surmise therefrom that in so far as the samples are representative of individual schools, we must be dealing with some variation in the availability of the schools of fish to the fishermen.

The averages of the lengths of the individual samples were calculated by Mr. Higgins and the frequencies of these averages are plotted for

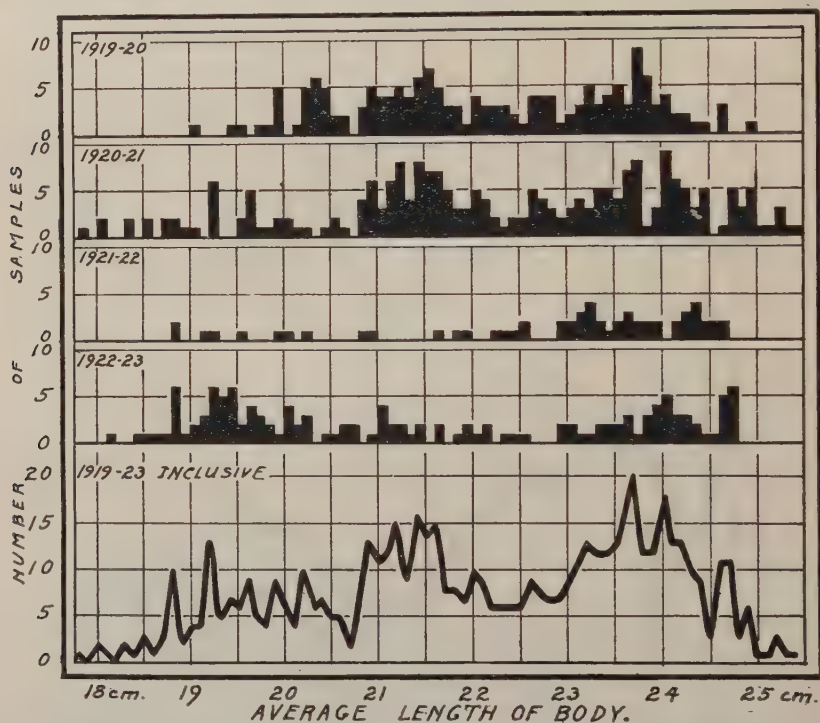


FIGURE 12. Number of samples taken at San Pedro whose averages fall at each millimeter of body length. Above, for individual years; below, summation of the four years.

the several years in figure 12. The summation of these for the four years combined shows the marked lack of samples averaging between 220 and 230 mm. The lack at 207 mm. is plainly due to the great variability produced by the incoming dominant group of 1922-23, and will very probably be filled in succeeding years.

To use the distribution of samples in 1920-21 for an example (figure 12), it is possible to separate them into two well-defined groups, one with a mode at 215 mm., the other with a mode at 238 mm. Were these to be separated and the size frequencies of the individual fish tabulated for each group, there would result two distributions overlapping to a

great extent, and their fusion would greatly obscure the fundamental division that exists. It is not necessary for our purposes that both of these groups be distinct, as the existence of either of them as contrasting with an otherwise uniform distribution would lead to the same phenomena which will later be remarked upon.

These two groups, whatever they may be, are most plainly shown when the separate samples are used as units. The consideration of size frequencies of the average lengths for the individual days shows that the division is not well marked. This is to be expected, as the samples on any given day vary considerably between themselves, and their combination by days leads to more median values.

The conclusion might be drawn that the schools at these middle sizes are not normally available, either because of their distribution in the fishing area or because of their habits. Such a conclusion does not include anything as to the relative fixity of the limits of sizes discriminated against, nor does it involve any decision as to whether the selection is strictly for size or for something allied with size, such as maturity or age.

These two sections at opposite extremes of the range of the frequency curves vary in their numerical relationship to one another considerably, as is shown by the annual deviations from the average ordinates.

(Figure 9.) Why this should be is not at once evident, but becomes obvious upon considering the errors of sampling which seem unavoidable.

Statistical Errors in Presentation.

There is a very marked error in the method of presentation, which extends to the method of sampling and to the catch itself (considered as a representation of what is actually in the ocean). The error of presentation is to be found in the treatment of each entire season's data and season's catch as a hundred per cent, so that the individual ordinates are represented as fractions of this as a unit. As a result the relative abundance of incoming abundant year-classes affects very markedly and adversely the ratio which the older ages form of the total for the season.

In our data, as presented in figures 6, 7, and 9, the variability of the incoming groups is, to a certain extent, lost and is only shown by an inverse variability of the older group. That is, when the incoming groups make up a larger percentage of the total, the remainder of older fish necessarily forms a smaller percentage, even though the actual numbers of the latter remain the same. Thus, even were the sampling system perfect in its representation of the abundance, the variability which should have been confined to one category of fish will be distributed among the others.

Nor is the statistical error purely a matter of presentation of the data. As may be observed, great numbers of fish appear at times, but the abundance is not reflected in the catch or the pack because the apparatus and machinery available can not care

The Error in the Catch.

for the abundance. The result is that in the catch itself, the less abundant "runs" of fish are given undue weight because they contribute as many samples to the total as the more abundant "runs," and the more abundant "runs" are neglected, resulting in a distortion of the relative importance of different sections. No possible system of sampling could avoid this error.

There is, also, a time element which may produce such an error independently of the limitations of the fishery. The samples were taken at equal, or nearly equal intervals of time, and it is very obvious that the time during which a particular size-group—as for instance that including the immature sizes—appears in the catch will vary independently and perhaps widely from the time during which the other—mature—sizes are running because of the multitudinous changes in the physical conditions of the sea, etc. To add to this the commercial demand oftentimes and admittedly curtails the length of the immature and the mature seasons differently. The use of the “total season’s pack” as a unit in the treatment of our data therefore introduces an error in that the percentage of this unit which is given to one “run” automatically alters the percentage assignable to other types of “runs.” This is the same error which arose from the statistical treatment which disregarded the limitations in capacity, but it is plain that in this case the error is inherent in the natural variation of abundance itself as well as in the statistical method or the machinery limitations.

The two groups lying on each side of 225 mm. may be expected to vary in their abundance relative to each other whether they are clearly separated or not. The variability of either of these groups must, by the nature of the errors in the catch and the samples, be expressed partly as an error of the other. So that in our individual graphs showing the deviation of the percentage ordinates of the successive seasons from the average for four years, it would be expected that the variability would be nearly equal and largely opposite in character on opposite sides of the division point. The fact that this is so nearly the case might possibly be taken to indicate that these two groups are the major varying divisions.

This variability as compared to one another would be especially favored by the fact that the smaller fish are taken in November and that the size increases until in late January and February it reaches a maximum rather abruptly, later decreasing to a medium size, with wide range. The distinctness of the seasonal change would, naturally, lend itself to errors of the type discussed, as the wide separation in time of run allows full play for variable length of canning operations, variable physical surroundings and errors due to the limited capacity of the gear; while the wide difference in sizes at different seasons allows the resultant variations in numbers to show very distinctly.

The striking lack of variability in the middle sizes needs some explanation. It seems to the writer, however, that this lack follows very naturally if the two major size groups mentioned are in any degree independent, as they would be if the period of transition were brief and accelerated, which there are some grounds for believing is the case. The results of the overlapping of two such independent groups may be seen from a consideration of two overlapping normal symmetrical frequency curves which vary in relative importance numerically.

Considering two normal frequency curves, 1 and 2, which overlap and are neither of them included wholly within the other, it is evident that in each curve the ratio of any ordinate, Y_1 or Y_2 , to the total number of individuals, N_1 or N_2 , varies from nearly 0 at the extremes of the range to a

value $\frac{Y_0}{a Y_0 \sigma}$ or $\frac{1}{a \sigma}$, where “a” is 2.507, Y_0 is the maximum ordinate and σ is

the standard deviation. On either side of the point at which the two curves cross, the series of ordinate ratios in one curve increases from left to right, and that of

the other from right to left, and the value of $\frac{1}{a\sigma}$ is not at all dependent upon the

magnitude of N or Y_0 . If these two series have common ordinates, there would be expected at one of these an equality in this ratio, and this ordinate may be determined by the following:

Let x_1 and x_2 be the distances from this common ordinate to the maximum ordinates of curves 1 and 2, and let $x_1 + x_2 = z$, or the distance between the maximum ordinates. Let σ_1 and σ_2 be the standard deviations of the curves 1 and 2, and let $m\sigma_1 = \sigma_2$.

Then,

$$x_2^2 = m^2 (x_1^2 - .4605 \sigma_1^2 \cdot \log m) \quad (1)$$

This may be solved for either x_1 or x_2 when σ_1 , σ_2 and z are known. x_2 is real when

$$(z - x_2)^2 > .4605 \log m \sigma_1^2 \quad (2)$$

It will be seen that the values of x_1 and x_2 are in no sense affected by the number of items (N_1 or N_2) or individuals included in the curves, nor by the height of the maximum ordinates (Y_1 or Y_2). It is affected by the value of z , the distance

apart of the maximum ordinates; and by the value of the ratio $\frac{\sigma_2}{\sigma_1}$, or m .

It must therefore follow that as long as a real value is obtainable for x_2 in (1), there is in the combined frequencies *expressed as per cents of the total*, an ordinate at which the variability produced by changes in the relative numbers in the two groups is at zero, and less than that at any other common ordinate between the two maximum ordinates.

It is possible, from a consideration of figures 1 and 8, to surmise what the minimum value of z could be and what the maximum value of m and σ_1 could be. If $z = 15$ mm. (the distance apart of the modes); $\sigma_1 = 20$ mm. (approximately that of the combined groups; $m = 4$ (should be more nearly 1); these values may be substituted in (1), and give a real positive value for x_2 ($x_2 = 4.4$ or 27.6). In our case the value 4.4 only, need be considered, and $x_1 = 10.6$. This is an extreme case, but (2) gives a real value for x_2 .

As a special case more nearly that which would apply, $\sigma_1 = \sigma_2$ and $m = 1$. Substituting in (1), and solving for z ; $z = 0$ or $2x_2$, whence the ordinate of no variation, Y_x , is midway between the two maximum ordinates.

In the actual data under consideration it would seem that some such grouping actually applies and the existence of ordinates between the two groups at which the variation in successive years is at a minimum must be expected. But, were that the case, it is almost certain that there would be some samples taken which would form a group occupying an intermediate position and cause a certain variability between the years at the point indicated as Y_x in the foregoing. But in so far as the two main groups would act as separate units and vary in their relative numbers, their combined frequencies, when reduced to a percentage form, would show a phenomenon of least variability similar to that shown in figure 10.

It might, however, be surmised that the standard deviation of either group would vary so widely from year to year as to invalidate this reasoning. It is not likely that this is so, however, for it can not be the dispersion of a compound group which must be considered, but rather that of the groups adjacent to the overlapping sections. And as may be seen, a change in the value of m , the multiple applied to the standard deviation, from 1 to 2 would be a large one, yet would not change greatly the position of the point of least variability. Using (1), if $m = 1$, $x_2 = .50z$, whereas if $m = 2$, $x_2 = .63z$, a change which would amount to about 2 mm. when the maximum ordinates were 15 mm. apart.

It should be particularly noticed that the existence of such separate "units" as these groups are, is not a clear cut matter. They are at best variable within themselves, and perhaps composed of other minor varying groups. Their distinctness must be a relative thing because of the existence of intermediate groups and because one of these large "groups" may be a constant, and the other in reality only a variable section of it. From a consideration of their characteristics it is evident that the frequencies of individuals within even a single sample of a single year's catch would constitute a similar type of unit, leading

to a change in the amount of variation present between the ordinate heights of the annual catch in successive years. Such change would be at a minimum at some one point intermediate between the mode of the sample distribution and that of any other sample, or groups of samples, considered, but might be totally obscured by the variability produced as a result of the grouping of a larger number of samples at different points. The fact that in the data from San Pedro there is such a very decided lack of variation at 225 mm. would be evidence of the relative distinctness of the two groups concerned, and of their magnitude, compared to the other groups existing.

There is, in fact, no doubt but that an intermediate group, or one having a distribution including that of both the others, could exist, giving to the ordinates at 225 mm. a certain minimum variability in proportion to the numerical strength and the variability of this intermediate group.

Again, there is no inherent reason why such units of variation as the two major groups should not occur in the catch in the same day, and within the same lunar period. Or indeed why, if they happened to be based upon some distribution of the schools related to the physiography of the sea or shore, both groups should not be consistently present throughout the season, in the same days, varying in importance simply through the variation in the fishing locality.

This variability and lack of variability constitute, it is apparent, the errors due to sampling, and are dependent upon the interplay of more or less indefinite groups, which in turn depend for their distinctness upon the length of time certain selective influences operate to form seasons or runs, upon the modification of the length of these seasons by the cannery demand, and upon the failure of the fishery to expand in proportion to the abundance. The errors due to chance selection of individuals must be minor in importance in comparison, and can be reduced by such precautions as are shown necessary by Mr. Sette.

The effect of these errors upon the catch and upon any conceivable sampling of that catch is profound, but their necessarily indefinite character seems to necessitate an extensive basis of observation and experience for their definition.

As has been remarked above, the forecasting of the run of fish depends, in so far as changes from year to year are concerned, upon

Persistence of Dominance. the persistence of dominance. It is certain, however, that the behavior of a year-class during its passage through the first group can be only a partial criterion of its behavior within the second, for the reason that the actual abundance of the first group relative to the second may not be correctly shown.

The early fishery, which seems to contribute the majority of the fish below 225 mm., may be supplied from one to two year-classes, as was the case in 1923, when there were three year-classes lacking, as shown by a comparison with the preceding years. However, the fact that the fishery drew upon a few year-classes rather than many, although it might have curtailed the part of the season dependent upon them, did not, necessarily, change the number of samples obtained, nor the period of time during which the first group predominated, in a proportion nearly commensurate with the lack of year-classes. Nor did

it prove anything regarding the actual abundance of those few from which it drew. In the final summation of data, the first group was not greatly lacking in numbers compared to the second, whatever may have been actually the case in the ocean at large. Therefore since we are lacking in any means of comparison of actual abundance, there becomes no way of prejudging the numerical rank of a year-class in the second group.

Yet there are grounds for believing that a reduction in importance would occur. It is certain that whereas the fishery has, during the prevalence of the first group which may be roughly coincident with a certain part of the season, but two or three year-classes to depend upon, it has in the second a very considerable number which accumulate at a certain maximum size when growth becomes inconsiderable. If the first group is divided among two year-classes, and the second group among ten, it must naturally come about that two year-classes of the same numbers in the ocean but belonging to these different major size-groups will be disproportionately represented in the samples, providing the two major size groups are given equal importance regardless of their actual numbers in the sea. As a result a great reduction in the relative importance of a dominant year-class could well be expected upon its entry into the second major group.

This may, indeed, not be by any means invariably true, for the exact reverse might occur, the real dominance of a year-class being suppressed by being limited to the first group and the early fishery, and its passage into the second group and later fishery bring to light its actual great superiority over other year-classes.

It is also worthy of attention that the existence of a distinct group not coextensive with the range of sizes existent in the ocean implies the existence of *selective* factors which produce this group and define its limits.

Action of Selection.

It is, accordingly, plain that a year-class approaching the upper limit of a group, as the range of sizes indicated by $B - B_1$ do during the years 1920-1923, must, if the upper limit of the group remains a constant one, be subject to increasingly effective elimination of the larger sizes, with the result of a lesser numerical representation and a displacement of the year-class modes as they approach the extreme of the group. The rate of mortality may also be very effective, in reducing the actual numbers present. Therefore it would seem very plausible to assign the changes in mode B to the reduction in number of year-classes, within the smaller size group, and to the decrease in their importance caused by selection for size and the rate of mortality. All of which is reflected inversely in the mode C by virtue of the representation of the whole season catch as 100 per cent and by the emergence from selection of its constituent year-groups.

It does not seem possible to do otherwise than await the passage of markedly varying year-classes through the range, in order to determine what the effect will be. It might be expected that the missing year-classes ("a" in figures 6 and 7) which are so distinctly indicated in our data, contrasting as they do with the years preceding and following, will, during their future progress, throw much light on the persistence of dominance.

If, then, there are distinct groups due to the errors of sampling such as appear to be present in our data from San Pedro, it must follow that a year-class during its passage through one of these groups will undergo alteration by varying degrees of selection. As

**Dominant Groups
and their Modes.**

we have seen, there is very pronounced evidence of selection for size upon the entering year-classes, as in 1923, and selection of some sort must necessarily be one of the formative agents whenever a group becomes distinct. If the first of the large groups we have distinguished extends as far as, or somewhat beyond 225 mm., as its upper limit of size, then it might fully be expected that a year-class approaching this upper limit would gradually lose its larger members, through selection, thus causing its modal and average length to be decreased, just as the apparent mode and average must be increased over what they should be during its entry into the group. The same sequence would be expected upon the entry of the year-classes into the second group.

To see whether this sequence actually holds as regards the position of the modes, the data available from San Pedro have been carefully examined.

The fact of selection is indicated by the change in numbers present in a year-class at different stages of its progress. The incoming year-classes are first heralded by a scattering representation, as in 1921 and 1922 (figure 1), which does not give the year-class its proper standing numerically. Upon once attaining its maximum in this regard it begins to decline as it approaches 225 mm. in size, as can be seen from the history of the group B-B₁ in figures 2, 5, 6, and 7. It becomes impossible to judge as to the actual degree of dominance of a group save when this cycle of changes is borne in mind.

These changes are selective in nature, and such selection must be largely for size, as we have seen when the male and female curves are compared in figures 3 and 4. The existence of this cycle of changes implies that in a series of year-classes of equal

Rate of Growth.

size passing through such a cycle that class which is midway in its transit will always tend to be shown as the maximum. Were these year classes fused or combined to form a compound group, this would necessarily mean that the center ordinate of the major group would remain the mode as long as the succession of normally represented year-classes kept coming. In figure 2, this seems to us to account for the presence of a mode at 215 mm. in the combination of 1919-20 with 1920-21, and its failure to progress in the combination of 1920-21 with 1921-22. The progressive encroachment of the lacking year-classes "a" in 1922-23 accounts readily for the growth shown in that year's data when the mode moved to 220 mm.

On page 167 above, it was said that, while it might be theoretically correct to determine the growth rate from the progression of the size frequencies of a group of year-classes, it was nevertheless well to examine such a theory with care. The practical dangers from such a method must now be clear, in so far as the following of a composite mode is concerned, for the growth of the composite mode may be different from that of any one of its constituent parts, due to progressive elimination of the various year-classes by selection and to the

varying weight they are given in the formation of the group at different times.

If the region $B-B_1$ in figure 1 should be a group of several years the group when first seen in 1919, was limited on its left, among the smaller sizes, but when seen in 1921, was limited as to the larger sizes, which had entered the zone in which they were supposedly discriminated against. The net result, as far as the group $B-B_1$, was concerned, must have been the consequent displacement of the modes and averages, and therefore too small an indicated growth, as we may see from the more diagrammatic presentation of the fused modes in figure 2, giving the years combined in pairs.

In figure 13 the growth as deduced from the modes in figure 2, where the seasons are combined in pairs, is shown in the upper graph. The progress of $B-B_1$, is plainly much less than the progress of B in the other graphs in the figure, as taken from figures 10 and 11 of Mr. Higgins' paper for the uncombined years.

If such is the effect of selection within a group compounded of several year-classes, there is every reason to expect selection to act vigorously within the individual year-class, altering the position of the modes. This has already been discussed, but it may be pointed out here that the effect of a selection of large fish when a year-class enters, and of small when it leaves the group considered, must be to indicate a lesser rate of growth during passage through than actually occurs. It is therefore a fair question to ask whether the growth shown in figure 13 for A and B is normal, even where no combination of years is made.

But whether this growth is normal or not, the temporary distortion would be of little importance were the year class easily traced for a number of years, for what was lost in one place would be gained in another. To hinder following a year-class as it passed from one size-division to another there exists the possibility that the modes are not strictly continuous in series. Were a year-class intermediate in position, between two groups, the lower group might show as a part of its frequencies a selection of small from the given year-class, with a mode at a correspondingly small length, while the higher division might show a selection of large, with a mode not at all coincident with the mode of the smaller sizes. In other words, a bimodal curve might conceivably arise from the same year-class. No direct evidence is at hand pointing toward an actual occurrence of this, however, and we must content ourselves with observing the modes with a questioning eye wherever two size-groups or divisions overlap.

Therefore in so far as growth is concerned the same conclusion holds regarding its determination as holds regarding the persistence of dominance; that experience only can tell. The passage through the range of sizes of some particularly well marked size-group, or of some lacking age-classes, such as "a," must be awaited.

The writer can not assure himself that the two major size-divisions seemingly indicated by the distribution of the samples are constant enough to justify any sureness as to the course of a year-class even within one of the divisions. The caution called for in the preceding paragraph might very well be made very general, and to apply within, as well as between, these indefinite variable units.

The different size-classes (whether in actual fact or in the catch as we sample it) in any one season have a certain numerical relationship

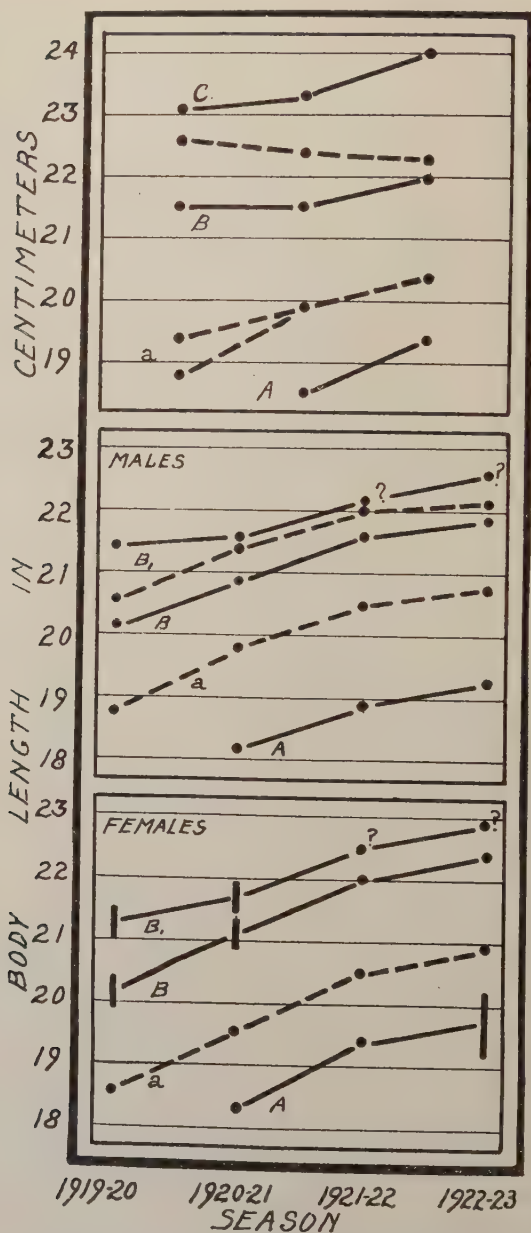


FIGURE 13. Progress of modes and depressions in size frequencies of San Pedro samples. Contrasting growth of mode B principally, but also modes A and B₁ and of the intervening depressions, as shown by the season's size frequencies (above) combined in pairs, and (below) by the same frequencies for males and females uncombined.

to one another. But it has been demonstrated that this relationship changes from year to year in accordance with the passage of dominant year-classes, and it is therefore impossible to look upon the groups indicated by the size frequencies in any one year as representative of the stages in the life history of a year-class. Starting as it does with a certain initial abundance, a year-class can not alternately predominate and decrease in numbers as do the successive size- or age-groups in our data for any one season. They do not, therefore, when observed at any given moment, afford any basis for prophesying the future of the catch.

Such a basis can be found solely in the history of individual year-classes or groups of these, followed in their course through the catch. The rate of decrease in abundance due to mortality, whether it is an even one or not, should hold true for any other year-class as long as conditions remain similar.

We find, however, as we have already seen, that our view of the course of a given year-class is probably much distorted by the conditions of selection and by the errors of sampling. And the question arises as to whether our future policy should include an attempt to eliminate the selection and the errors. Would such be successful, or offer any hope of success? And what is the ultimate need of so doing?

There is, of course, no possibility of fully extending the limit of smaller sizes, of eliminating the neglect of these by the gear used. To devise an apparatus which would take every size of sardine indifferently, an entire revolution in the method of fishing would be necessary, since the peculiarities of the gear and the visibility of the schools to the fisherman are very vital in the present methods. Even supposing such a revolution might be possible if special scientific gear were used, the use of this on one vessel would be totally inadequate to sample the many different schools into which the sardine population is split. There must always remain, lacking this perfection of gear and of sampling, an increase in abundance of a year-class as it enters the commercial sizes and a decrease as the rate of mortality overtakes this rate of increase, or as the year-class passes out of the particular group of selected sizes it has entered. *The given year-class under observation must needs be observed in its relationship to this cycle of changes, which must be determined by experience.*

Furthermore, were it possible to accomplish the practically impossible and devise a perfect method of sampling, it would result in a knowledge of the actual abundance in the ocean, but not of the catch. It would still be necessary to attain an understanding of the actual catch as selection and its errors of sampling affected it, and to retranslate our knowledge of actual abundance into terms of the actual catch, since this is what really interests mankind. It must therefore be much simpler to eliminate any determination of the actual abundance of different sizes of fish, and to proceed directly toward accurately defining the cycle of changes through which a given year-class must pass in the catch, and to define its actual abundance in relative terms.

The relationship of the year-class at its entrance to this normal cycle must be relied upon to define its subsequent relationships as it attains different sizes. If it has twice the average representation for a beginning class, it would be expected that this ratio, or a ratio hav-

ing a definite relationship to it, would apply throughout its course within the first major group.

It follows from this that if, as there may be reason to believe, the catch consists of one or several distinct units, seasonal or regional, which vary in their importance to the catch and independently of each other, each of these must be regarded separately, and the ratio of abundance of the observed year-class determined as it enters each unit or group. It therefore becomes of importance to ascertain the degree of independence or relationship between these groups, something which must be done through observation and experience.

As the definite future program for this phase of the work upon the sardine, there is therefore proposed the following of the commercial catch by the most adequate and representative system of sampling possible. From the data obtained must be followed the course of those size-groups which may affect the commercial catch, be they composed of a single year-class, of a fused succession of dominant classes, or of lacking classes.

It is, from the point of view of the future program, of great interest to define the most adequate and representative system of sampling. We have been unable to find any radical need for change from the present method except what exists in the possibility of weighting each sample by the amount of the commercial catch it represents. The time for doing this is not ripe, however. Moreover such weighting would not be as much a change in method of sampling as it would be a development of the present one. The present samples must be the basis for any future system.

That the time is not ripe for a system of weighting is apparent from the fact that at present the greatest source of confusion as to abundance comes from the failure of the receipts of the canneries and the boat catch to expand or shrink in accordance with fluctuating abundance. The minimum abundance during the season is too apt to be sufficient. This may not always be true, but even in the face of a depletion of the fisheries, the difference between the greatest and least abundance in such a fishery as that for the sardine will be such as to render the maintenance of enough machinery to care for the greatest abundance impossible from an economic standpoint.

Perhaps a system of weighting may develop from a consideration of the number of hauls necessary for each boat catch, but even then there is to be reckoned with such additional factors as the varying accessibility of schools of different sizes and condition, and the residue of other factors we have previously mentioned. We can not see, in fact, any possibility of so handling any conceivable system of sampling as to render the larger varying groups of sizes definitely fixed in their numerical relationships one to another. And in so far as this is true we must await the results of experience before stating what these relationships are. In other words we must wait and see whether a year-class which appears dominant among the smaller sizes remains so among the larger, or to what extent its dominance is likely to alter.

There is another phase of our sampling which needs attention, however, and that is a more scientific mathematical adjustment of the numbers handled in each sample to the number of samples per day. In view of the great variability between boat catches as compared to

the small variability within the boat catch, it might be desirable to increase the number of boat samples and reduce the number of fish taken in each sample. This is, however, something in the nature of a refinement of method which can not alter profoundly the main conclusions of our study.

In conclusion it must be said that at present any forecasting of the "catch" of sardines (pilchards) is limited. And it will be limited—until we have had a longer period of experience—to the sizes below 225 mm., the changes in which we have particularly observed and which are at present most

Conclusion.

important to us. Nevertheless, so clear cut and overwhelming are the variations between the year-classes which have during the past four years entered the commercial catch, that the rosier hopes may be retained. We are most hopeful that the normal course of an age-class through the various peculiarities of the catch, etc., may be defined within narrow limits, and that the course of a certain age-class through a group may finally prove to give some indication of the relationship that class will hold in the other groups. Our work has certainly not gone far enough to indicate the contrary and it has gone far enough to give us definite grounds for our forecasts, limited as these are.

That work of this type seems to assume a statistical rather than a biological character is very true. But we deem it true, also, that there can be no biological explanations advanced for phenomena which are not known and defined. If the catch and its limitations are not known, there is little use in advancing theories of migration, of varying mortality, etc. The things explained very likely indeed would never have existed. The path to the goal of a perfect understanding of our fisheries is a long and hard one, but because of that there is no great utility in refusing to locate the objective, nor in neglecting to define the direction in which the path must be pointed.

Our program may be accurately and definitely stated as a continuation of precise observation of the catch so that we will be in a position to define and foretell its changes, and so that our biological studies may be brought to a practical application. The success of our efforts in the past justifies such a continuation.

THE SARDINE AT MONTEREY:
DOMINANT SIZE-CLASSES AND THEIR
PROGRESSION, 1919-1923

By
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This paper is No. V of a series published by the Fish and Game Commission of California in Fish Bulletin No. 11, and is Contribution No. 56 from the California State Fisheries Laboratory. It was submitted for publication virtually in the present form in 1925.

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THE SARDINE AT MONTEREY: DOMINANT SIZE-CLASSES AND THEIR PROGRESSION, 1919-1923.

By W. L. SCOTFIELD.

The problem.

As conservation is the intelligent use rather than the hoarding of a supply, it would be desirable to know the amount of sardines available and to determine just what proportion of this stock could be used each year without depleting the future growing stock; in a sense, to determine the capital so that only the interest could be drawn without depleting the capital. It is impossible by any known method to determine with accuracy the growing stock of a pelagic fish such as the sardine, so that we are reduced to the necessity of using the trial and error method, that is, using a portion of the stock each year till the first signs of depletion appear. It is the duty, therefore, of the Fish and Game Commission to carefully study the fishery so that the first danger signs of depletion may be detected and this, briefly stated, is the object of our sardine investigation.

Methods of detecting depletion.

The total catch is no indication of the abundance of fish without a careful consideration of the many other factors directly affecting the catch, such as number of boats, gear, fishing methods, demand, and general business conditions. The catch of one certain boat using the same methods and gear throughout a series of years would indicate serious depletion when it occurred, and this is one of the two principal methods to be employed for detecting depletion. The other method should give us more fundamental knowledge as to the growing stock and is the one upon which our efforts have been concentrated. This method is to determine the normal proportion of size-classes in the catch and by watching this proportion in the future to discover any changes from the normal. One of the first signs of a heavy drain upon a species is a lessening of the proportion of larger or older individuals; thus an abnormal scarcity of the larger sardines would be an indication that this species was subject to a heavy drain, and that the first stages of depletion were occurring.

When employing either of the above methods, or in any such consideration of depletion, it is necessary to have some understanding of fishing methods, gear, and trade conditions. A detailed description of methods and gear with a résumé of trade conditions for the Monterey sardine fishery has been prepared for publication.

Natural and artificial fluctuations in abundance.

Depletion might be caused by adverse conditions for spawning and development or the increased activity of natural enemies, but depletion through a series of years may be the result of man's overfishing. However, a change in the abundance of fish is not necessarily caused by overfishing and fluctuations in abundance due to natural causes may be of greatest importance to the fishery. Natural fluctuations are beyond the control of man since we can not govern such conditions as spawning habits, migrations or temperatures, and are not apt to accomplish

much in controlling disease, parasites and the great losses due to the feeding habits of other fishes. Artificial fluctuations resulting from such causes as the extent of fishing, localities and seasons fished, gear, and fishing methods in general are of course within our control. It is necessary not only to determine what fluctuations in abundance exist but to explain the cause, so far as possible, in order to distinguish between natural and artificial causes. A study of possible depletion either from overfishing or from natural causes involves an analysis of the fluctuations in abundance of the stock. Since it is impossible to take a census of the stock in the ocean, we are dependent on an analysis of the commercial catch as an index to that stock. The catch* does not give a true picture of the stock in the ocean in that it takes only the fish that are found close to the surface relatively near the canning plants during the canning season, and, at Monterey especially, the commercial catch avoids the smallest sizes. However, a careful watch kept on the catch from year to year will undoubtedly enable us to detect major changes that might occur in the ocean stock.

Variety in size fluctuations.

The commercial catch shows many and complex fluctuations which necessarily delay progress in the solution of our problem, that is, the determination of the normal proportion of size-classes so that future changes from the normal may be noted.

The fish caught by one haul of the net are not all of exactly the same size, although there seems to be a tendency for sardines of one general size to segregate into schools. Hauls made at different times and in different localities on the same night may yield differently sized fish. The catch of one boat for a night differs somewhat from that of other boats as to sizes of fish caught. The sizes of fish caught are not just the same for any two successive nights, so that there is fluctuation in sizes from day to day within any short period, as a week or month. There is decided fluctuation in size from month to month in any one season. There is also the major fluctuation between seasons. The change from year to year, or the natural fluctuation in abundance of size-classes, is of greatest importance from a conservation standpoint, but requires several years' data for comparison. The data already collected show clearly that such major changes do occur in the natural abundance of the various size-classes from year to year. The available data also give a fairly clear idea of the change in size within a single season.

*Since the amounts of sardines sold to fresh fish markets are almost negligible, we use the term "commercial catch" in referring to the cannery catch, and the two terms are synonymous for all practical purposes but, strictly speaking, the commercial catch might be divided into cannery and market catches, the latter being but a fraction of one per cent of the total. During the years here considered there were very few sardines delivered to packing plants which used any other method than canning, so the term "cannery catch" is here used to mean sardines delivered to packing plants. Since 1923 other packing methods have been employed so that in future reports a distinction between canning and other packing methods will be necessary. There is practically no catch of sardines in California other than the commercial catch, except small amounts used as bait in albacore, salmon and mackerel fishing. Therefore, the terms "catch" and "commercial catch," as used throughout this paper, refer to cannery catch, that is, deliveries to packing plants.

Purpose of this paper.

It is the purpose of this paper to present the fact that there are major fluctuations in the Monterey sardine catch from year to year due to natural fluctuations in the abundance of size-classes. It is not the intention to give here complete demonstrations of the many fluctuations in size-classes to be found within a single season, but to confine ourselves to the major changes from season to season, leaving to subsequent bulletins the discussion of minor fluctuations. However, the principal minor changes within a season will be briefly touched upon in order that we may better understand the data of any one season since such data are in reality the resultant composite of data for individual days, weeks and months, each of which shows minor size fluctuations which have a distinct bearing on the question of contrasting yearly catches.

Rather than to consider a calendar year as a season, it is more logical to conform to the fishing and canning season which, at Monterey, is roughly from June of one year to March of the following calendar year, a period of from eight to ten months (see graph No. 1). Before discussing size fluctuations as shown by our data, a brief description of the data themselves is here given.

Time covered by sampling at Monterey.

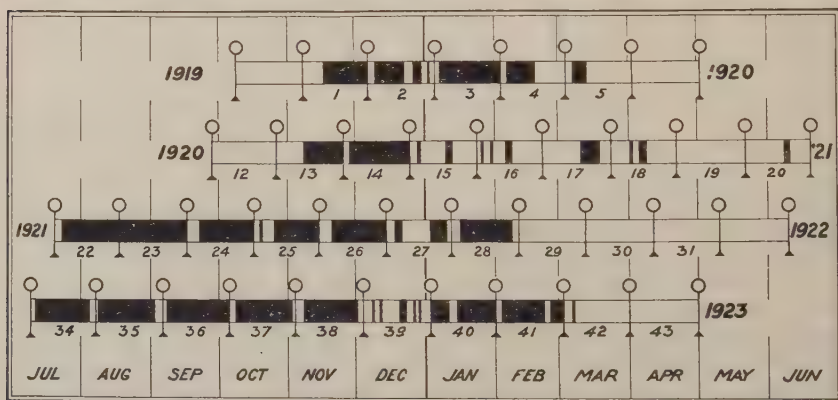
Up to the present time (summer of 1925) six consecutive fishing seasons at Monterey have been covered by careful observations of the commercial catch delivered to canneries, but this paper will deal only with the first four seasons, that is, from November, 1919, to March, 1923, inclusive. During these first four seasons, samples of the catch were taken each day that fish were delivered to the canneries throughout the season or portion of the season covered, with but very few exceptions. The first season's data (1919-1920) were collected by O. E. Sette and covered the time from November 17, 1919, to March 13, 1920. Two or three months of that fishing season had passed before our work was organized sufficiently to begin sampling. Data for the three following seasons were collected by W. L. Scofield. It was not possible, because of limited personnel, to begin the work of the second season before November 8, 1920, a date about midway in the fishing season. This was unfortunate because during the later part of this season (January to June, 1921), the canneries were closed much of the time or operated but a few days at a time due to financial depression and the unfavorable rates of foreign exchange. As a result, the only continuous data obtainable during this season were from November 8 to December 25, 1920, but observations were made to the end of the season on all days that canneries received fish. The following, or third season, was covered completely by daily sampling from its opening in June, 1921, to its close in February, 1922, with the exception of one break of several days at the Christmas-New Year's holidays. The canneries closed early this season because of limited sales in the post-war period. A complete series of daily samples was taken through the entire fourth season, from July 10, 1922, to March 10, 1923.

Graph No. 1 is presented to show the portions of each fishing season covered by daily sampling, represented as solid black areas. The circles, indicating the time of the full moon, divide the seasons into lunar months which have been numbered serially. Calendar months are indicated by vertical lines to show the relationship between lunar and calendar months.

Method of sampling.

Conditions in the sardine fishery at Monterey differ somewhat from those at San Pedro, and the method of sampling and measurement followed by us at Monterey differed in several details from the practice followed at San Pedro. For this reason the methods of sampling, notes recorded, and methods of measurement employed at Monterey are here briefly summarized.

In order that the samples should be as representative of the catch as possible, the chances of unfair sampling were carefully considered before work was started. If there was a variation in the fish



GRAPH No. 1. Portions of lunar and calendar months covered by daily sampling.

from day to day, the interval of time between observations would be of importance. The preference for certain fishing grounds by each crew might cause a constant variation in the catch of different crews. The fact that crews fished at somewhat different hours of the night and in different localities made it necessary that all boats should be represented in the sampling. The variation in the canning plants as to methods and possible preferences for certain sized fish necessitated including all the canneries in the sampling and preferably in proportion to the amount of fish each received.

One hundred was chosen as a convenient number of fish to be handled by one person each day, and a sample of twenty fish was taken from each of five boats each night. The sampling was distributed among all the boats delivering so that each boat was represented every few days. Each cannery was represented in proportion, roughly, to the amount of fish it received. A sample was taken from a boat at whatever stage in the unloading process happened to occur when the observer arrived at the cannery, except that a sample was seldom taken from the first few hundred pounds of fish unloaded. This ran-

dom choice was not only more convenient, but it precluded the possibility of unfair sampling that might be due to a sorting of fish sizes in the lighter during transportation to the cannery. The boat sample was taken in the cannery while the load was being delivered, and every reasonable precaution was taken to insure the sample being as representative of the boat catch as possible. Each boat sample was measured separately and each was numbered serially for convenience in tabulating and in referring to notes. As it was deemed unwise to trust any agent to gather any of the fish for measurement, each observer personally collected the sample at the time of boat delivery at the cannery. We were fortunate in being able to carry the same schedule through these four seasons without important modification in method and without change in personnel during any one season.

Notes recorded.

The fishing area at Monterey is unusually restricted and the conditions influencing the fishery are comparatively uniform, so that this locality furnishes an excellent opportunity for a detailed study of a fishery, especially for an analysis of the size fluctuations within one season. For this reason there were recorded at Monterey detailed notes as to boat catches. The following information was recorded after questioning a member of the crew of each boat from which a sample was taken.

1. Serial number and date of delivery.
2. Name of the crew or captain.
3. Name of the cannery to which delivery was made.
4. Total catch of the boat that night.
5. Limit in tons set by the cannery for the crew that night.
6. Number of hauls made.
7. Time of night each haul was made.
8. Tons of fish caught at each haul.
9. Locality of hauls—number of miles off what point on shore.

In most cases the captain of the crew was questioned. A successful effort was made to establish a friendly intimacy with each crew captain so as to explain to him the object of gathering such notes, for in this way suspicion was soon disarmed, and it was found that most of the men answered questions to the best of their ability. Although the answers of any one crew could not be accurate, the averaged information so gained gives a very true picture of the fishing conditions. In addition to the above notes gathered from each boat crew general notes were made on the weather each night that deliveries were made. The weather notes were:

1. Sky—clear, cloudy, foggy, rain.
2. Wind—direction, none, light, moderate, heavy.
3. Sea—calm, moderate, rough (choppy or swells).
4. Air—warm, cool, cold.

Personal observations on air temperatures being of so little value, we have obtained records of air temperatures from a self-recording thermometer. At irregular intervals general notes were made on conditions affecting the fishery, such as severe storms, strikes, special holidays, accidents, by-products, methods, gears, demand, markets and general business conditions.

Method of measurement.

When ready for measurement, fish were laid out on a table and the scales at the base of the caudal fin scraped away so as to expose the skin at the termination of the caudal peduncle. Measurements were made on a board provided with a fixed millimeter scale, and a sliding arm which supported a thread constantly at right angles to the scale. The snout of the fish was pressed against a fixed metal stop shaped as a shallow V so that a uniform and constant position on the board was insured. The body of the fish was placed on the board parallel to the scale. By sliding the arm, the thread was brought to the chosen position on the fish and the measurement was read from the scale with sufficient accuracy to the nearest millimeter. The body of the fish was pressed gently against the board so that it lay flat, the caudal fin remaining in a natural position. The first measurement or "body length" was made from the tip of the snout to the termination of the skin of the caudal peduncle (base of the caudal fin). The ventral lobe of the caudal fin was then swung to a position nearly parallel with the millimeter scale, and the "total length" of the fish taken from tip of snout to extreme tip of longest ray of ventral lobe of caudal fin. After a few hundred fish had been measured, a table was made showing relationship between body and total lengths and future measurements were referred to this table. The chief object of this was to catch up mistakes in either measuring or recording the figures. Carbon duplicates were made of all original data. Fish were laid in a pan in order of measurement, opened by a knife cut along the ventral side, viscera were pulled aside, sex of the fish determined and recorded. All fish of the first season were measured by O. E. Sette. Measurements for the following four seasons were made by W. L. Scofield.

Tabulation and weighting of samples.

Since total length was more variable, body length was adopted as the measurement to be used. The body length measurements of each boat catch sample were transferred to a separate sheet, arranged in order and sexes segregated. From these sheets the data were combined for each day, and daily summaries were combined by weeks. Weekly summaries were then combined into lunar month totals, each step in the tabulation being carefully checked.

It sometimes happened that less than five boats delivered on one night so that, on the basis of twenty fish from each boat, less than one hundred fish per day could be measured in such cases. In order that a single day's sampling could be compared with other days, the total number of fish measured on such days was weighted to one hundred by treating each measurement by the necessary factor. This was inconvenient as it necessitated carrying fractions in compiling data. Beginning January 1, 1922, sufficient additional fish were measured to bring the total number of fish for the day up to one hundred, thus obviating the necessity of weighting. For example, on a night when four boats delivered, the regular samples of twenty fish per boat were taken, totaling eighty fish, and five additional fish were measured from each of the four boats, thus totaling one hundred.

Tables presenting original length frequencies of each sex for each

sample, even tables for each lunar month during the four seasons here considered, would be too extensive for publication in such a paper as this. The range of fish sizes being from 90 to 290 mm. (body length) would require lengthy tables and more than 2000 boat samples (41,500 fish measurements), involving 28 lunar months, are considered. Frequencies were combined in various ways, smoothed, reduced to percentages, and in some cases deviations from averages were calculated so that final tables would be of little assistance to the reader except in checking the plotting of the graphs themselves, and even such tables would be rather cumbersome for printing. It is almost necessary, therefore, to omit frequency tables from this paper.

All original length frequency data, as well as all data connected with each step of the various methods of treating frequencies, are on file at the State Fisheries Laboratory for the use of anyone seriously interested in this branch of research.

Tables to show the number of fish measurements used in compiling the length frequency data pictured in graphs Nos. 4 to 11A inclusive:

GRAPH No. 4.

Season 1921-1922.

Lunar month	No. of fish
22-----	2,000
23-----	2,600
24-----	2,300
25-----	1,700
26-----	1,500
27-----	800
28-----	1,800
Total-----	12,700

GRAPHS Nos. 5, 6, 7 and 8.

Lunar month	Male	Female	Both sexes
1-----	741	855	1,596
13-----	734	766	1,500
26-----	705	795	1,500
38-----	870	1,030	1,900
Totals-----	3,050	3,446	6,496

GRAPH No. 9.

Lunar months	Male	Female	Both sexes
1-3-----	2,426	2,871	5,297
13-16-----	1,954	2,146	4,100
26-28-----	1,880	2,220	4,100
38-40-----	2,170	2,831	5,000
Totals-----	8,430	10,067	18,497

GRAPH No. 10.

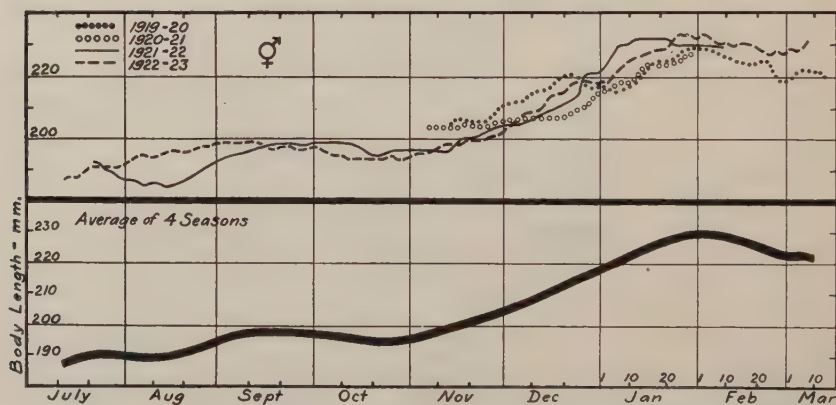
Lunar months	Male	Female	Both sexes
1-5-----	3,426	4,274	7,700
13-18-----	2,512	2,588	5,100
25-28-----	2,663	3,137	5,800
38-41-----	3,137	3,963	7,100
Totals-----	11,738	13,962	25,700

GRAPH No. 11.

Lunar months	Male	Female	Both sexes
1-5 -----	3,426	4,274	7,700
13-18 -----	2,512	2,588	5,100
22-28 -----	6,153	6,547	12,700
34-41 -----	7,597	8,403	16,000
Totals -----	19,688	21,812	41,500

Fluctuation within one season.

Roughly, the fluctuation in size of fish through a season is from small in summer to large in winter. Average lengths, although somewhat misleading, are useful in showing this general change in size. The sardines caught during the summer months of April, May and June average small. The average size increases steadily through the late summer and fall months with the largest average size during January and February. During March and April the average size drops rapidly to the very small fish of early summer. This seasonal change from small in summer to large in winter is clearly shown by



GRAPH No. 2. Showing (above) the trend of daily average lengths of fish for four fishing seasons, and (below) the average of the four trends.

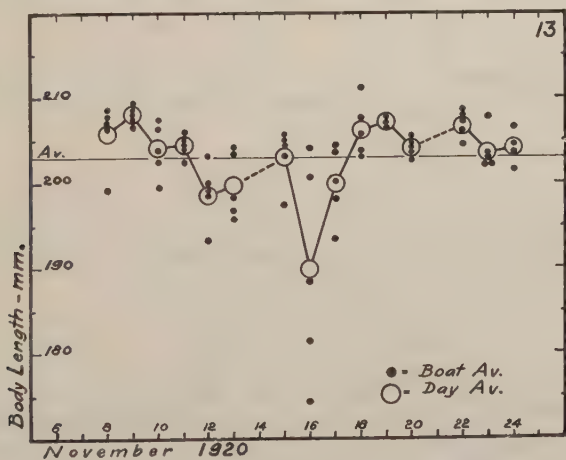
graph No. 2 presenting daily average lengths for four seasons. In order to show merely the trend through the season, the daily averages were smoothed once by a moving average of 29. The graph shows also a decided similarity in trend for each season, the differences between the seasonal trends being only minor. Since there is a progression in size of fish through a season, this must be considered whenever attempting to compare different portions of any one season or in comparing dissimilar portions of two or more seasons.

Fluctuation in average size from day to day.

There is decided fluctuation in the size of fish caught in any one portion of a season and the general trend of sizes as shown by smoothed average lengths differs for one month as compared with other months of that season. Within any one month, there is considerable variation in the average size caught from day to day. As explained elsewhere, the day's catch is represented in our data by samples from five different boat catches. There is variation in the average size of fish caught by

different boats each night, as illustrated in graph No. 3, which shows only a portion of one month merely to illustrate the variation from day to day and the differences in average length of individual boat catches. In this graph the dots represent the average size of fish caught by each of five boats on each night, and the circles connected by a heavy line represent the average size of all the fish of the sample for each night.

There are the further variations in average size of fish caught in different hauls of the same boat on the same night, as well as differences in size of fish caught in a single haul; but there is no need to take these up here, except to state that there is evidence leading us to believe that even the fluctuation in sizes caught by different hauls of the same boat catch is not due to chance, but is of real significance and dependent on fundamental causes. It is apparent, then, that the catch of any one day is a composite made up of several boat catches, each of which is composed of several component variables, the individual net hauls.

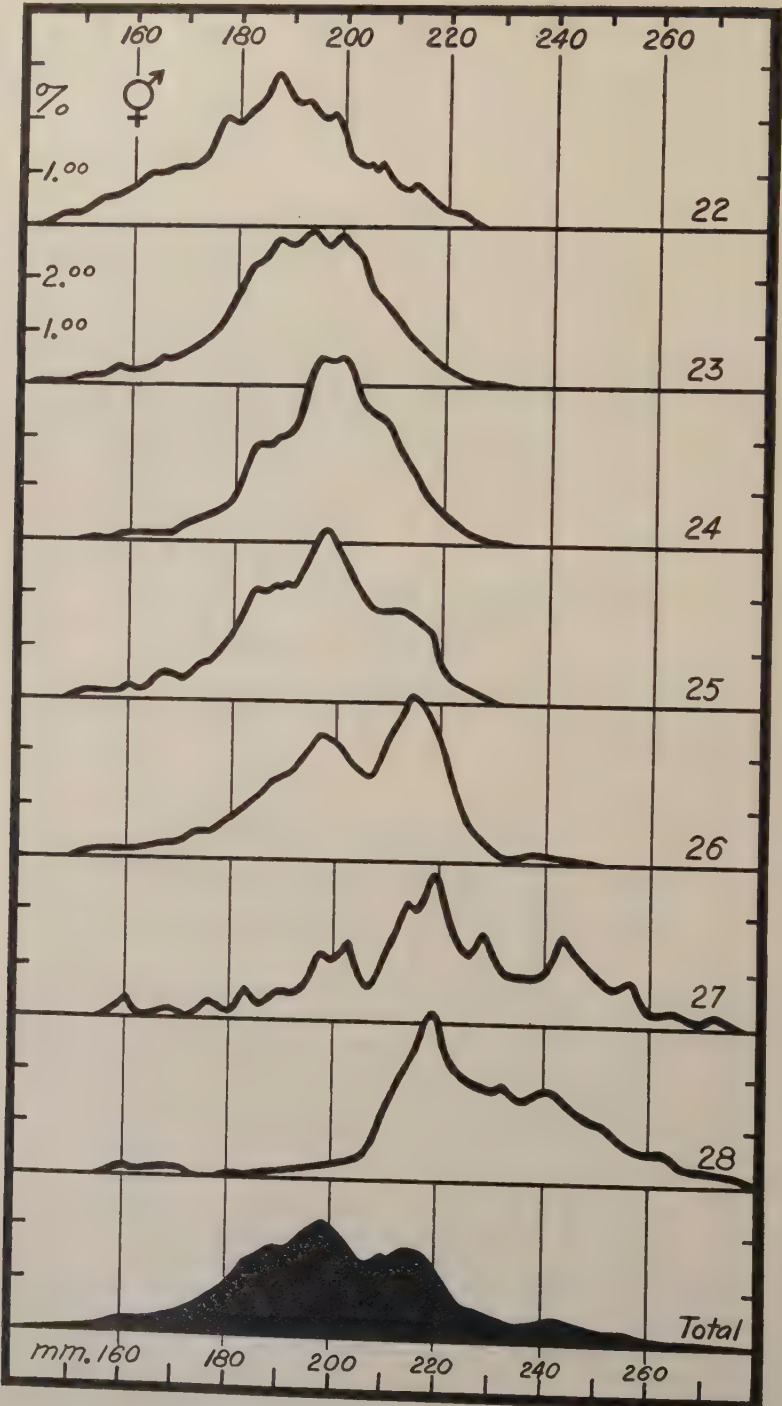


GRAPH No. 3. Boat and daily average lengths of fish for a portion of one lunar month (13).

The total catch of one month is the aggregate of several composite days, and the season's catch is a total compounded by summing six to ten aggregate months. It will be well to consider briefly the composition of some one season to illustrate the fact that, since the season is built up by summing variable monthly catches, the final result is dependent on the composition of the component parts or monthly catches.

Frequency distribution by months for one season.

In the preceding pages, average lengths have been used to show the type or trend of fluctuations in size, but averages fail to give the proportion of small to large or the relative representation of each size-class. The change in size of fish caught during a season from small in summer to large in winter, is well illustrated by the length frequency distributions at various times during the season. Graph No. 4 shows such distributions for the season 1921-1922, grouped into lunar rather than calendar months. Curves representing unequal numbers of fish have been rendered comparable by plotting at each ordinate



GRAPH No. 4. Season 1921-1922 length frequencies by lunar months.

the percentage of the total frequency of each curve, rather than the actual frequency.

Over eighty per cent of the fish in the commercial catch during the July-August lunar month (No. 22) of this season (see graph No. 4) were smaller than 200 mm. in length, but by the close of the fishing season about ninety-five per cent of the fish were larger than 200 mm. in length. It will be noticed that this increase in size during the season is not a gradual and uniform progression from month to month, as one would expect if the increase were due to the growth of one size-class through this size-range in one season. Size-classes appearing in the catch become dominant and drop out later as the season progresses. The same size-class appears month after month, but in varying proportion to the other size-classes, so that the progression in average size is the result of the changing proportional representation of the several size-classes present in the catch. For example (graph No. 4) the size-class centered roughly at 196-200 mm. is well represented in the first lunar month (22) but smaller fish predominate. In the third and fourth months (24 and 25) this class dominates due to the dropping out from the catch of the smaller sizes. In the fifth month (26) the class is only a little less abundant, but there has been a decided jump in dominant size to much larger fish (centering around 216-220 mm.) with a relative scarcity of the 201-210 sizes. By the end of the season (lunar month 28) this 196-200 class is scarcely represented while sizes larger than 230 mm. have appeared and with the dominant size (216-220) make up practically the total catch. However, the 196-200 size-class, having been consistently abundant earlier in the season, is the class most abundantly represented when these seven lunar months are combined to make up the season's total catch. It is evident that the composition of the catch for one season is dependent on the proportional representation of the several size-classes in each of the lunar months making up the total or season's catch.

The catch for any one lunar month is the summation of individual boat catches, and its character is determined by the relative abundance of the various size-classes as they appear in boat catches night after night throughout the month. Since boat catches differ so markedly, one or two boat catches, if taken as representative of the monthly catch, might give a false picture of the catch for that month. The true picture is obtained only after the complex variations have been summed, in which case minor variations sink to relative unimportance and the significant features stand out more prominently. Thus if any one size-group dominates in a monthly catch it is apparent that this size has recurred in abundance in the several boat catches on many of the nights of the month, although it might be almost lacking in certain boat loads. Graph 4B is presented as an illustration of the fact that the monthly catch is a summation of variables and is not to be judged by a single boat catch. In this particular case a random choice was made of a boat sample representing one hundred fish (dots), which were plotted in connection with the monthly total (solid line) of which they formed a part. A light broken line has been plotted to indicate the appearance the monthly curve would have had if all nights of the month had yielded only the sizes of fish shown by the one boat sample.

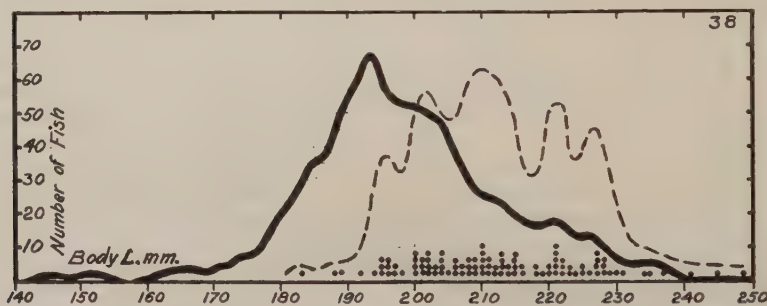
The dominant size-class 191-195 mm. of the monthly curve (solid line) happens to be practically lacking from this boat sample, and an

examination of the data for this month shows this class to be relatively lacking for two or three consecutive nights, but very abundant night after night for a period of about three weeks during this month.

The significant feature is, that in spite of the complex variations in the data making up each monthly curve, the same size-classes persist month after month, but in varying proportion. If differences exist between the catches of two or more seasons the real significance is to be found in the size-class composition of the monthly catches. For this reason we will present data contrasting similar portions of four seasons before comparing the four total seasons.

Selection of comparable portions of seasons.

In order to compare in detail one portion of a season with other seasons it is necessary to select comparable periods from each season. As has been pointed out, there is considerable variation in sizes of fish from day to day, and until the nature and causes of these variations have been more carefully studied, we are not justified in selecting a short period of but a few days for comparing with another season. There is some evidence indicating a periodic fluctuation in sizes of fish



GRAPH No. 4B. Shows length frequency for one boat sample of 100 fish (represented by dots) in relation to the total frequency (heavy solid line) of one lunar month. The broken line shows the appearance the monthly curve would have had if based only on the one boat sample.

conforming to the lunar month (at least during the late fall and winter months) so that the calendar month as a time unit is open to objection because it includes unequal portions of lunar months from year to year (see graph No. 1). Furthermore, the fishing and canning periods at Monterey conform to the lunar rather than to the calendar month with a cessation of activities for several days at the time of the full moon. We have, therefore, adopted the lunar month as the more logical unit.

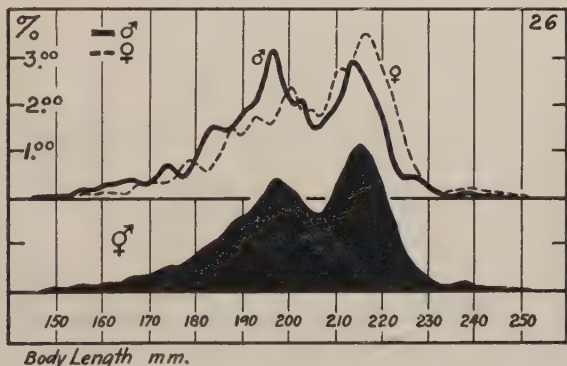
Sexual dimorphism and proportion of sexes.

In this species the rate of growth of the females is greater than that of the males. Within the range of sizes most abundantly represented in the catch (190–220 mm. body length) the females are about four mm. larger than the males, and graph No. 5 is presented merely as an illustration of this fact.

This difference in size is sufficient that in more detailed studies of size fluctuation and in the consideration of such questions as rates of growth, location of modes or determination of age, it will be necessary

to handle the sexes separately in spite of the disadvantage of reducing by half the number of measurements for any given period of time.

Another consideration: the proportional number of individuals of each sex, represented in a size-group, becomes important because of the differential growth rate in the sexes. In a size-group of which 50 per cent were males, the mode of the curve of the males would be about four mm. short of the mode of the females. Combining the sexes would throw the mode halfway between. In case the males outnumbered the females, the mode of the curve of sexes combined would not be halfway between, but would be nearer that of the male mode. If females predominated the combined curve would then show larger fish than in the case where females were 50 per cent of the total. In graph No. 5, note that in the curve of sexes combined there is a mode at about 197 mm., the location of which is largely determined by the abundance of males of 196 mm. length rather than by the females of 200 mm. In the larger group (215 mm.) the combined curve is affected less by the males at 213 than by the somewhat greater number of females at 217 mm., although the proportion of the sexes is more



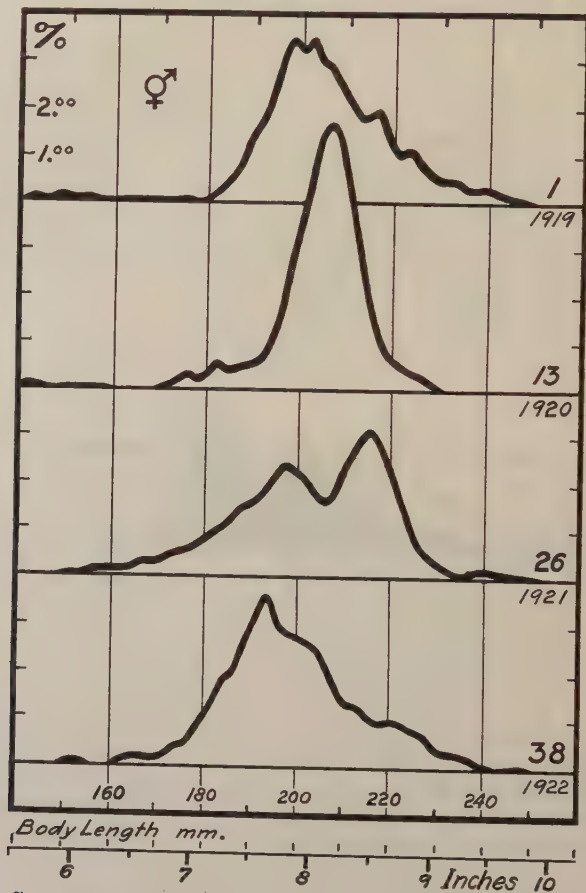
GRAPH No. 5. One lunar month (26) to show more rapid growth of females. Solid black curve represents both sexes combined.

nearly equal than in the group of small fish at 197 mm. The segment of the combined curve from 217 to 225 mm. is largely determined by the females, but this is due more to their rapid growth than to preponderance of numbers in the group as a whole, although the females outnumber the males at any one ordinate in this restricted range. This illustration is by no means an isolated case, as the four months of November to February show the same tendency, that is, a large proportion of small males to small females and the reverse proportion in the larger size-groups. It was not the intention here to enter into an analysis of this complication; it was intended only to point out that the two questions of sexual dimorphism and proportion of sexes represented tend to distort modes and lessen the distinctness with which modes show themselves when the sexes are combined. In graph No. 5 within the range 160-195 mm., the curve for each sex shows distinct modes, but these are lost when the sexes are combined. They were not of sufficient prominence to survive and only the distinctly dominant modes persist.

This question of differential growth and the relative numbers of each sex is then but another complication in the composition of the curves presented, and renders still more significant the fact that certain size-classes appear and dominate from year to year in spite of the many variables in the composition of the catch.

November catches of four years contrasted.

The lunar months corresponding roughly to November of the four years, 1919, 1920, 1921, and 1922, are here presented as an illustration



GRAPH No. 6. Length frequencies of lunar months corresponding to November for four consecutive years.

of the fact that any one size-class is *not* represented equally in the monthly catch of four different years. (See graph No. 6.) The November lunar months were selected for comparison because they represent more complete data for the four years than do any other four comparable lunar months. (See graph No. 1.)

In the first year (November, 1919) the most prominent group centers around 200 mm.; the following year the sizes near 206 mm. are overwhelmingly dominant. In the third curve (1921) the sizes near 216

are most prominent, although a group of smaller fish (near 197) is well represented, but the intermediate sizes, which were so prominent in the preceding year, are relatively lacking. In the last curve, small fish (190-195) dominate. It is apparent that one group of fish dominates in the first three curves, but each succeeding year it is present as larger fish due to growth during the intervening year. In the last curve (November, 1922) it is passing out of the catch and is no longer the dominant group because of the appearance of a new incoming prominent group of small fish.

These four lunar months are not strictly comparable in that this cross-section of the four seasons includes somewhat different calendar portions of each season. This may be important since November falls in the transitional period between small summer fish and larger winter fish. (See graph No. 2) Furthermore, data are lacking for a considerable portion of the first two lunar months, which would be a serious consideration in a study of minor fluctuations in sizes. These two discrepancies, in addition to differential growth of the sexes, varying representation of each sex and the complex of the many other variables already mentioned, will tend to conceal in some cases or to exaggerate and distort in other cases the appearance of size modes, but they are not sufficient to obscure the principal outstanding feature, the appearance of a dominant size-class and its progression from year to year through the size-range of the commercial catch.

Graph No. 6 shows well the dominance of certain size-classes, but the data in this form do not so clearly indicate that other size-classes are relatively lacking; that is, not only lacking compared to other sizes of the same month, but relatively lacking compared to the average representation of that same size-class over the period of four years.

The average* of these four months resembles a normal frequency curve with intermediate sized fish (a little over 200 mm. in length) forming the mode. (See graph No 7.) Using this average curve as a base, the deviations from this average curve were plotted for each of the four lunar months, so that in any one month, frequency greater than the average appears as solid black area above the base or average, and relatively lacking frequency is shown below the average line.

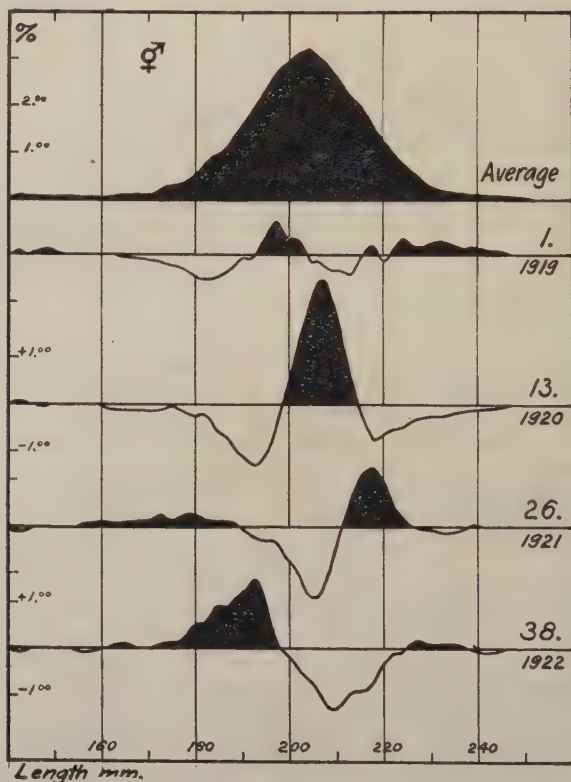
In graph No. 6, it was apparent that one dominant size appeared during the first three years. Presenting the data as departures from the average, as in graph No. 7, shows this group more clearly at, roughly, 195-199 mm. in 1919, 205-209 in 1920, and at 215-219 in 1921. The group still persists as somewhat above average representation in 1922 at, roughly, 225-229 mm. It is obvious that the relatively lacking size-classes, as well as the abundant sizes, appear in the catch more than one year and progress from year to year, due to the growth of the fish each year. The rate of progression seems fairly regular as one would expect of the growth rate within the rather restricted size-range of the commercial catch. The determination of the exact rate

*Throughout this paper the standard practice in handling length frequency has been to smooth the actual frequency twice by a moving average of three to eliminate minor insignificant fluctuations. Smoothed frequency at each ordinate (each mm.) was then converted into a percentage of the whole so that curves of unequal numbers of fish might be comparable. In other words, each curve was weighted to 100. The average of four such curves was obtained by summing the weighted frequency (in the form of percentages) and dividing by four to give a simple average or arithmetic mean at each ordinate.

of growth within this range, with the slight decline in rate to be expected, as well as a discussion of the irregularities and changes in abundance from year to year of any one group, would involve an analysis of the variables inherent in the curves, and this is outside of the scope of this paper.

Separating one sex from the data as above presented has the disadvantage of reducing the number of fish measured by approximately one-half.

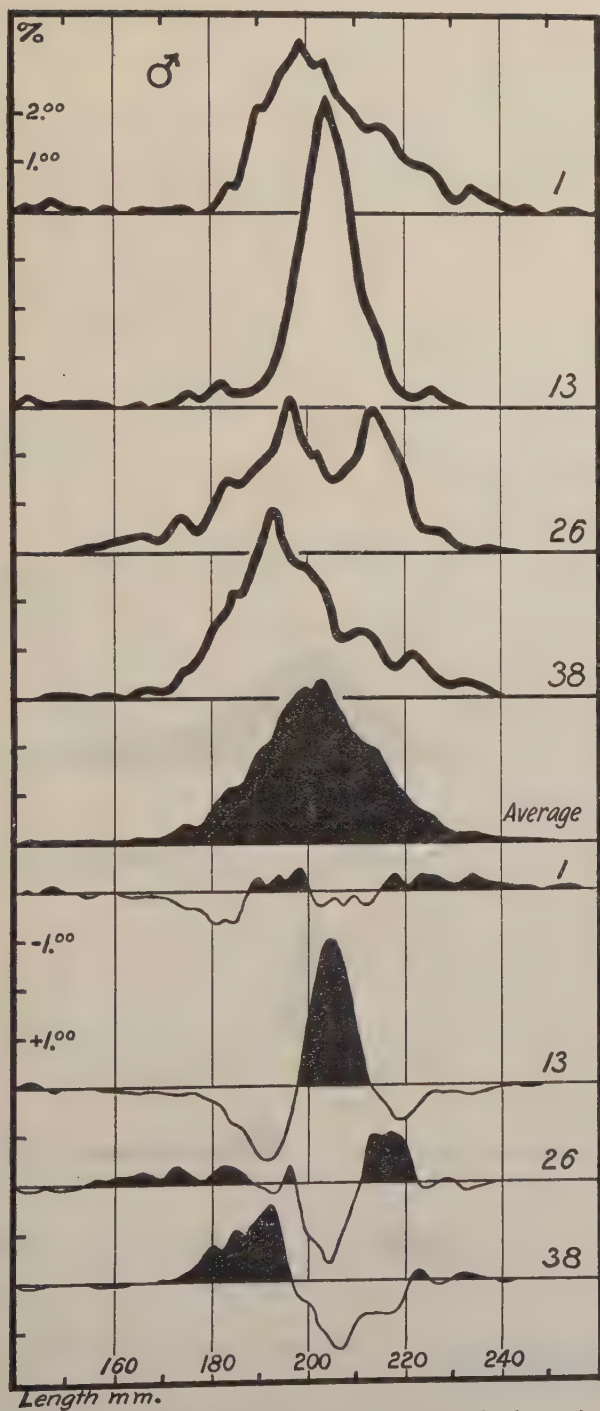
The male fish of the same four lunar months, as pictured in graphs No. 6 and No. 7, are presented in graph No. 8, showing the four length frequency curves above, with the average of these as a solid black



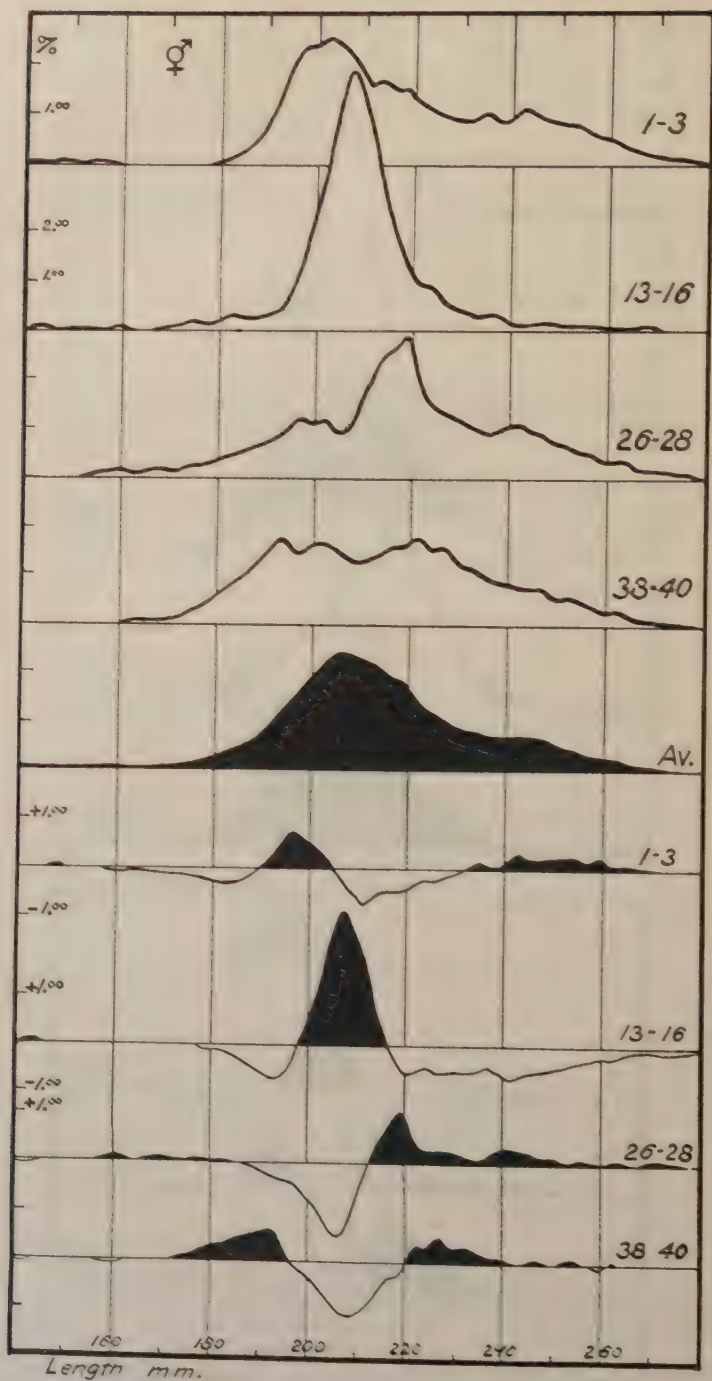
GRAPH NO. 7. The solid black curve at the top is the average of the four monthly frequencies of graph No. 6. Below are shown the deviations from the average of each of these four curves, using the average as a base.

curve, and the plus and minus deviations from the average as solid or open portions above or below the average.

The small irregularities or jagged appearance in the curves of graph No. 8 result from the reduction in numbers of fish making up the curves. Modes are naturally located at points 1 or 2 mm. less than in the case where both sexes were pictured as combined. The relative proportion of small, medium and large fish has been altered slightly by eliminating the female, particularly in lunar month 26, which has



GRAPH No. 8. Males segregated from the fish shown in graphs No. 6 and No. 7.



GRAPH NO. 9. Combined November, December and January curves for four consecutive seasons.

been discussed under "Sexual dimorphism and proportion of sexes." The same modes and relative lacks appear at almost the same places, they progress from year to year in the same way and their relative importance remains very nearly the same as in graphs No. 6 and 7. Plotting the females alone gave results so nearly identical that little would be added by presenting the graph here. It is evident that these features are so fundamental that they have not been materially modified by segregating the sexes.

Comparable portions of the four seasons.

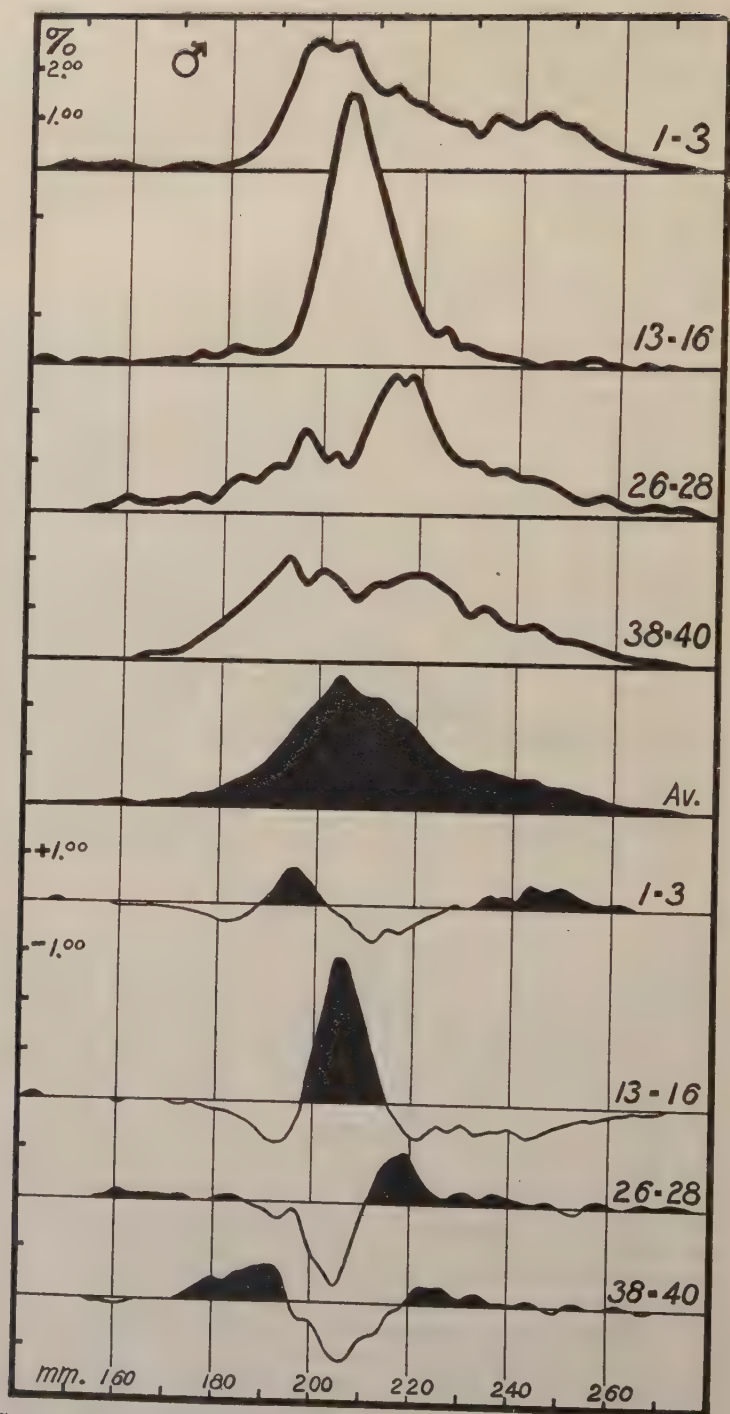
The fishing season of 1920-1921 was so interrupted by the financial depression of that year that our data are fragmentary, making it difficult to use this season's data as a whole even for comparison with the data for the preceding year, which covered about the same calendar months, but was almost complete for the time covered. (See graph No. 1.) These two seasons include only the winter and spring months from November to March or April, but entirely omit the summer months from July to October inclusive. During the two following seasons (1921-1922 and 1922-1923) data were collected from the opening of the canning season in July through to the close of the season in February or March, so these two complete seasons (though similar as to time covered) are not comparable, as to time covered, with the two preceding incomplete seasons. There is, also, between the second and third seasons, a difference of two months in the time at which fishing ceased for the season. This is of importance because through February, March, and April, there is a decided change in the catch, the larger winter fish being supplanted by the small fish of summer and the second season, closing in April, includes fish not fully represented in the catch of the third season which closed in February. The data most comparable for these four seasons fall in November, December and January, the months including the largest winter fish.

November-January portions of four years compared.

The selection of the comparable three months portion (November, December, and January) of the four years is in reality adding to the November curves (shown in graphs Nos. 6 and 7) the fish caught during December and January, which fish average the largest of the year. (See graph No. 2.) Naturally the size distributions of the November curves are altered by this addition of large fish as is shown in graph No. 9.

Increasing the representation of large fish has not obscured the principal features shown in graph No. 7, but in some cases has emphasized them. The exact position and relative prominence of modes has been somewhat altered as is to be expected, but the same modes appear at about the same positions, dominate, and progress from year to year. The same relatively lacking size-classes show year after year, and progress from year to year with the growth rate of the fish.

When departures from the average are compared in graphs Nos. 7 and 9, it will be seen that there are several minor differences. In both graphs the outstanding dominant group (at about 195 mm. the first year) progresses almost to 230 mm. in the fourth year, but in the curve of November alone (graph No. 7) it is not prominent due to the meager



GRAPH No. 9A. Males segregated from the fish shown in graph No. 9.

representation of very large fish in the November catches. In the January-December curve of this fourth year (graph No. 9) this size-group is much more prominent, due to the greater representation of large fish. It is almost equal in prominence to the new group of small fish appearing below 200 mm. This new group in the fourth year shows in graph No. 9 as less pronounced than in November alone, which is to be expected since adding large fish reduces the relative abundance of small fish. Evidently, the December and January catches of this fourth year included very few fish smaller than 200. This is borne out by an examination of the monthly catches of not only this season, but of the other three seasons as well. (For example, see graph No. 4.)

A similar instance is shown in the progression of the relatively lacking sizes next larger than this outstanding dominant group. This group of lacking classes progressed through the four years, as shown by the November cross-section of the season (graph No. 7), but the addition of the large fish of December and January has obliterated this lack in the second and third years of graph No. 9. On the other hand, the relatively lacking sizes next *below* the chief dominant group have persisted and progressed through all four years in both graphs No. 7 and No. 9, with only slight modifications, because the scarcity of fish of these sizes was so pronounced that altering the time of our cross-section of the four seasons has had little effect. However, the lack of these sizes is a little less prominent in graph No. 9 at 185 mm. the first year; 193 mm., the second year; and at 210, the fourth year. The lack of sizes in the neighborhood of 205 mm. the third year is about the same in both graphs No. 7 and No. 9, and shows not only in the plotted deviations but in the percentage frequency as well. (Graphs Nos. 6 and 9.)

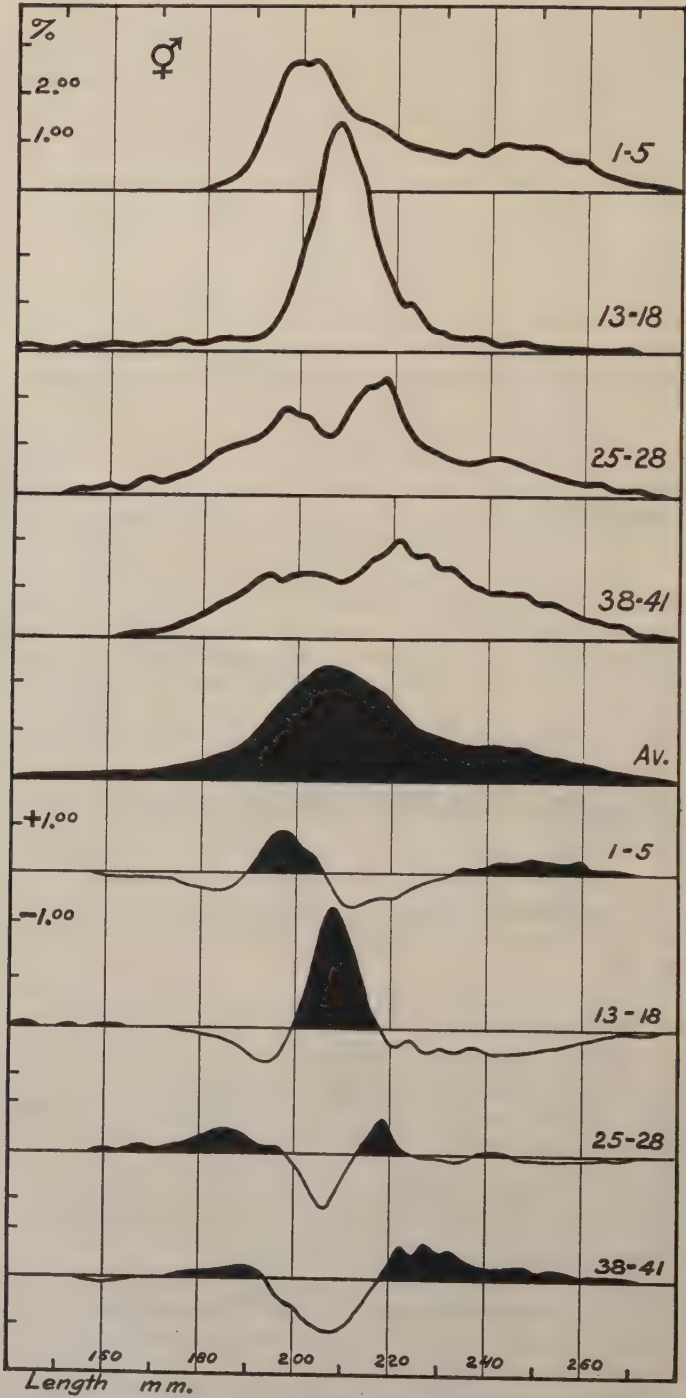
In graph No. 9A, the males have been segregated from the fish shown in graph No. 9. The effect of reduced numbers and modifications due to differences in the two sexes of fish are scarcely noticeable in comparison with the persistence of the conspicuous features of these curves. The appearance and progression of dominant size-classes has not been altered nor has the regular annual advance of lacking classes been obscured.

The first two seasons compared with similar portions of the next two seasons.

Comparing the November to April period in the four seasons includes all of the first two seasons' data, but the spring months are unequally represented in the four seasons as has already been mentioned. This would have the tendency to include, in unequal proportion, the small fish that frequently appear in late March and April, but the result of combining the November to April months is very similar to that shown in graph No. 9, except that introducing a greater time range has added minor variations. (See graph No. 10.)

In graph No. 10 the same dominant and relatively lacking groups appear at approximately the same positions and progress from year to year in the same way. The curves showing departure from the average are very similar to those of graph No. 9.

In the simple frequency curves of graph No. 10, there are minor changes in the third and fourth year curves from those shown in graph



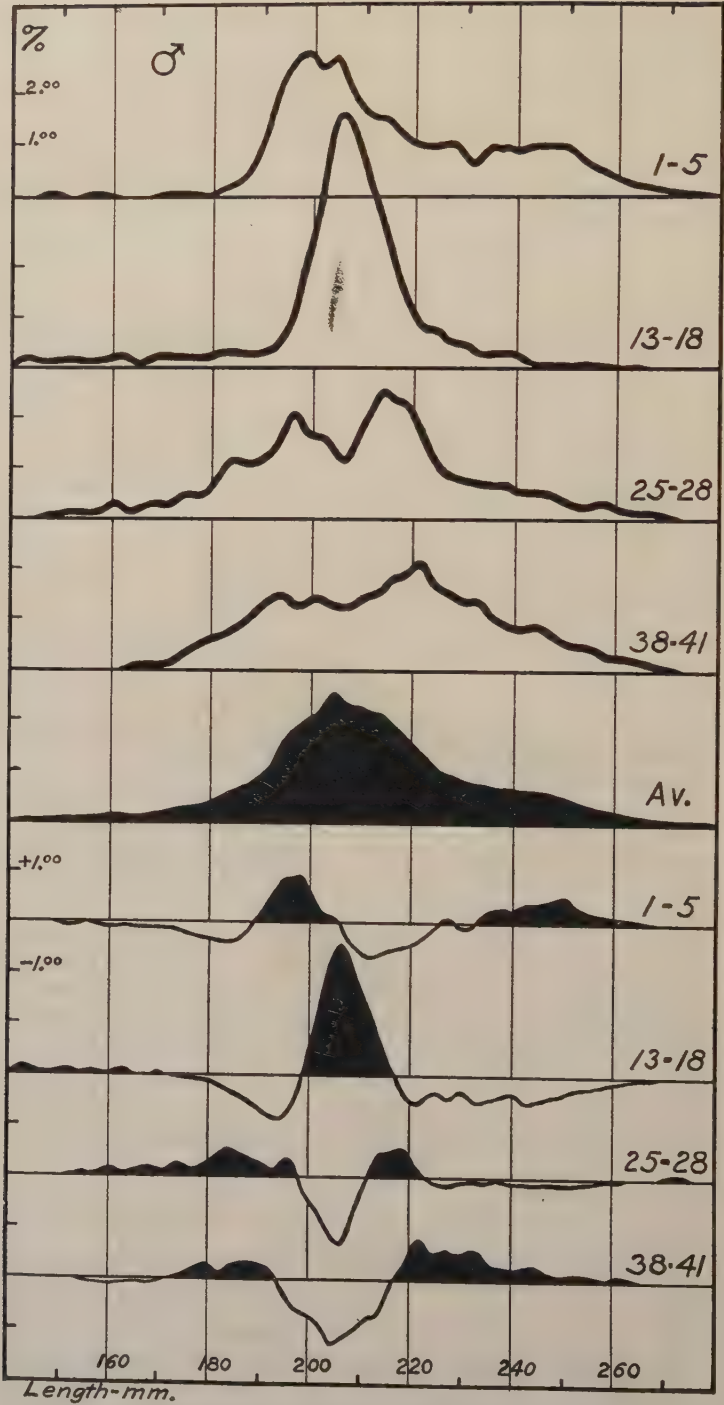
GRAPH No. 10. November to April portions of the four seasons.

No. 9. The change in the frequency distributions for the third year (25-28 of 1921-1922) of graph No. 10 is of interest as illustrating the importance of one of the variables in the composition of this curve, the change in size of fish from small in summer to large in winter. In compiling the data of the third year for graph No. 10, lunar month 25 (see graph No. 1) was included, but not illogically so, since most of the data taken during this lunar month (falling half in October and half in November) are included within the calendar month of November. Without lunar month 25, this curve would be identical with that shown in graph No. 9. Including lunar month 25 introduces, in the composition of the curve, a larger number of fish of the 190-200 sizes than would have appeared had the compilation of data started with the next following month (26), as was the case in graph No. 9. A reference to graph No. 4 furnishes the explanation of this, as lunar month 25 is seen to resemble more the summer fish; 26 is a transition period and the following months include almost exclusively large fish. The small fish of lunar month 25 have altered the frequency curve of the third year of graph No. 10, so that it does not resemble the corresponding curve of graph No. 9 as much as does the curve for November alone (graph No. 6). The addition of small fish has merely increased the prominence of the mode below 200. This alteration in the range of time included in the cross-section of this season has introduced a variation in the average size of fish caught, but this has had the effect only of slightly modifying the relative prominence of the two modes in the curve. It has in no way altered the fact that these two modes are dominant as compared with the average of the four years, and the sizes between the two modes are likewise lacking as compared with the average year. Obviously, lunar month 25 is made up of the same size-classes as are shown in the following months of that season (graph No. 4), but in different proportion. Adding lunar month 24 to graph No. 10 would further emphasize the mode just below 200 mm. and thus correspondingly reduce the prominence of the mode just below 220 mm.

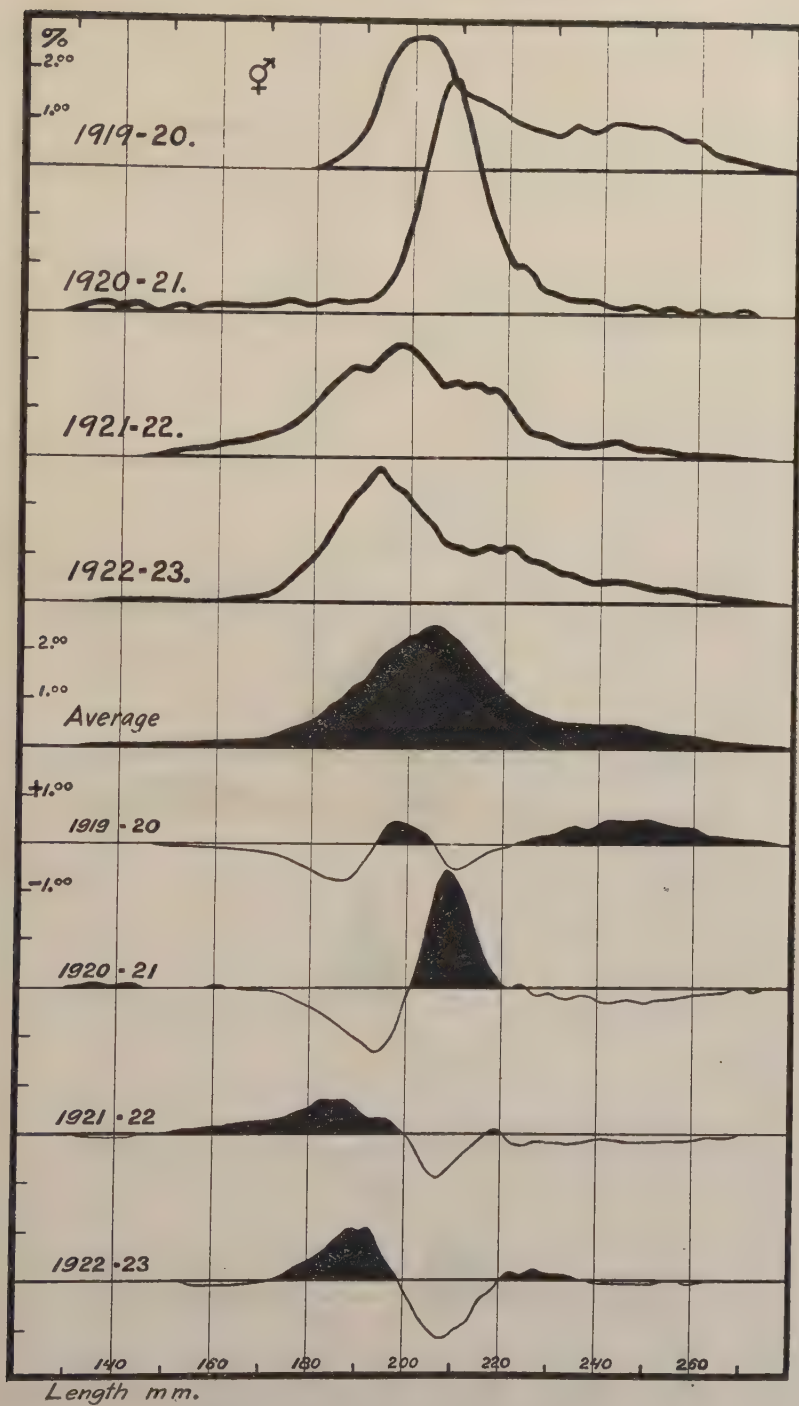
Eliminating the females of graph No. 10 and plotting only the males as in graph No. 10A has introduced small irregularities due to reduction in numbers of fish and slight alteration in the relative numbers of fish represented at certain sizes. Segregating the males has had very little effect in modifying the prominent features, the progressive appearance of one dominant size-class, the entrance and progression of a small size-class and the annual advance of relatively lacking classes through the four consecutive years.

Total seasons contrasted.

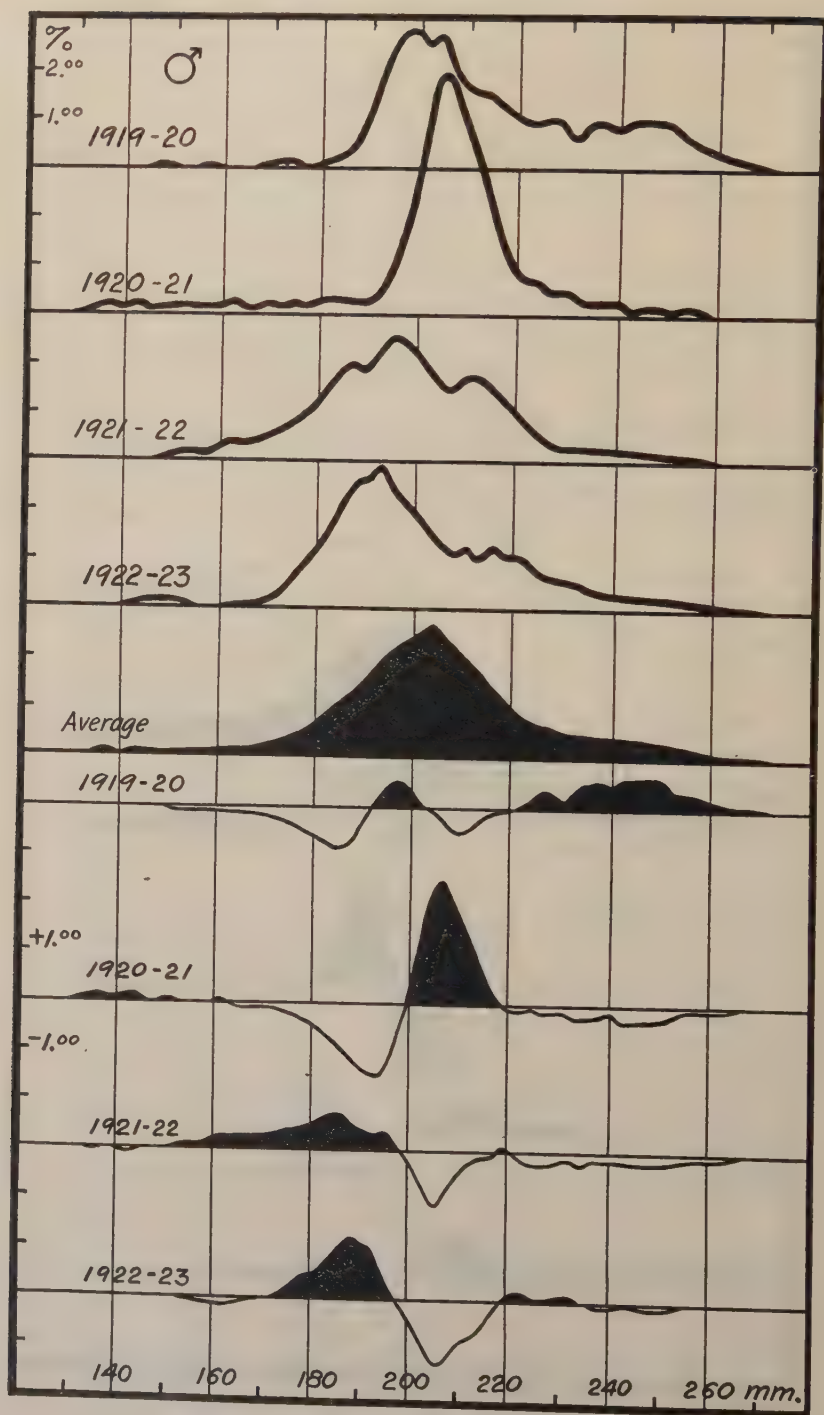
Combining all the length frequency data obtained for an entire season is of interest in picturing the season as a whole for comparison with other seasons, but in the four seasons under discussion, the first two seasons omit the small summer fish, as already explained (see graph No. 1), and are, therefore, not comparable with the third and fourth seasons which include the summer as well as the winter months. The four seasons are presented in graph No. 11, in which the first two and the last two seasons are roughly comparable, but in considering



GRAPH No. 10A. Males segregated from the fish shown in graph No. 10,



GRAPH No. 11. Four seasons compared.



GRAPH No 11A. Males of the four seasons.

the four together, it should be remembered that the small fish are lacking from the first two curves. This is noticeable in the scarcity of fish below 200 mm. length in the first two years.

The addition of the summer fish present in the catch in the last two seasons has had the effect of greatly altering the appearance of the frequency curves of graph No. 11, as compared with graph No. 10. The third and fourth curves have been changed from fish averaging large to fish averaging small, and dominant size has been reduced from about 220 to less than 200 mm. This has had the effect of modifying the *average* season (solid black curve) so that in graph No. 11 the sizes from 180 to 210 mm. are more abundantly and sizes larger than 210 mm. less abundantly represented than in graph No. 10.

The addition of large numbers of small fish, below 200 mm. length, has the effect of reducing the percentage of fish larger than 200 mm. in the last two years. Therefore, size modes above 200 mm. would appear with less prominence in the last two years than would be the case in data dealing only with winter fish. This effect is evident in graph No. 11. Modes smaller than 200 mm. would be emphasized by the addition of the small fish of the last two years. These effects would not be so noticeable when comparing these frequency modes with the average season (solid black curve), which has been modified in a somewhat similar way, yet the addition of summer fish has had such a pronounced effect that the deviation curves of the third and fourth years of graph No. 11 clearly show the reduction of modes near 220 mm. Likewise, the deviation modes between 180 and 200 mm. appear much more prominently in graph No. 11 than in graph No. 10.

Such differences in the prominence of various modes are to be expected, but the comparing of such dissimilar data has not obscured the fundamentals of the data. Certain features remain outstanding in spite of the change in average size and relative numbers of fish represented in the various size-classes. The same modes as noted in graphs Nos. 6 to 10 were sufficiently dominant to persist here, and their progression from year to year with each season's growth has not been altered. Likewise, the relative lack of certain size-classes persists and progresses from year to year, being merely altered but not hidden by changes in the numbers of fish represented in each size-class.

Segregating the males from graph No. 11 and plotting them separately in graph No. 11A has made but slight alteration in the curves, except that the modes of the male curves appear at points about two mm. less than in the curves of combined sexes. The exact size distribution within the areas above average or below average is not just the same for males as compared to combined sexes, and this is shown in graph No. 11A as slight modifications in the shape of curves of deviation from the average. The recurring appearance and progression of dominant sizes and lacking size-classes has not been altered by subtracting the females, showing that differences in rate of growth of the sexes and varying numbers of fish of each sex in the various size-classes are of minor importance compared with the prominent feature of these curves. The dominant sizes and relatively lacking sizes are so overwhelmingly dominant or so decidedly lacking as to subordinate other features of the data.

Variation in abundance of size-classes from year to year.

It has been shown that the abundance (percentage of the total catch) of any one size-class in the catch for a given year varies with the seasons of that year. A more important question is the relative abundance of each size-class from year to year. For reasons discussed elsewhere the annual total catch of fish as an index of abundance is highly misleading. An examination of the relative abundance of size-classes in the catch over a period of years is of great significance in determining and explaining fluctuations in abundance. If we found each size-class equally represented in the catch from year to year, it would indicate that the conditions governing the reproduction and growth of the sardine had varied but little, since fishing methods have remained practically constant during the course of this investigation. A material change in any one of several conditions could cause a variation in the relative abundance of size-classes. The more important of these conditions may be mentioned briefly, the most obvious of which is the number of fish of spawning age available for reproducing the species, since abundance depends fundamentally on the number of eggs laid. A complex of physical conditions govern the successful hatching of the eggs and growth of the young, such as temperature, air and ocean currents, storms, and composition of water. The abundance of proper food supply is subject to variation and, of course, is of prime importance throughout the life of the fish. The toll taken by natural enemies may not remain constant from year to year. A host of conditions govern the rate of mortality, which rate we assume from analogy to be high at first and to decrease through middle life, but our chief concern is with the constancy or variation in abundance over a period of years. A decided change in the present stock of spawning fish would mean a similar change in the future stock, resulting from the present spawnings. In the first place, it was essential to determine whether or not there was fluctuation in abundance of size-classes of fish from year to year. Since marked changes do occur, it should be determined whether natural or artificial causes (as man's fishing) are responsible and to what extent each is responsible; but no matter what the cause, the question of greatest concern to the sardine industry and to the conservation of this fishery, both for the present and the future, is the fact that decided changes do occur from year to year in the abundance of the various size-classes.

The dominance of a certain size of small fish in the catch of one year is very apt to be repeated the following year in the next larger size due to the growth of this class during the year. As a particular size-group of fish is undoubtedly present in the catch for several years, the decided dominance of one size may be traced through four or five successive years. In like manner, the relative lack of certain size-groups may be traced through the years in which they appear in the commercial catch. If, for one or two years, spawning and early development of the young were unusually successful, the effects would show as an abundance of small fish a few years later when these fish reached the lower range of commercial sizes. A year or two later the catch would show a preponderance of medium sizes, and still later an unusual number of large fish. Partial failure of spawning or early

development for two or three consecutive years might well result a few years later in a temporary failure of the fishery for the most desirable canning sizes, and a more protracted period of failure of the incoming sizes would mean financial ruin to many of the canning companies as at present organized.

Although the prediction of future fish generations resulting from spawnings of the present stock is now impossible because of our limited knowledge, it may be possible to predict the relative abundance of sizes that may be expected in the catch for two or three years in the future. Such prediction would be based on an analysis of the dominance or relative lack of size-classes in the present catch. Any such prediction would be more accurate if supplemented by a study of the abundance of fish smaller than those appearing normally in the commercial catch, since there is selection at the lower end of the commercial size-range. The two smallest size-classes are only occasionally included in the catch, the smallest class rarely appearing and then only as a few scattered individuals as representatives of a class that must, in the ocean, outnumber any other class. The relative abundance of the next entering class would naturally be an important consideration in the catch of the following year.

Conclusion.

It is most unlikely that a possible change in this new and carefully observed fishery, either in methods or amounts of catch, could explain such differences in size-classes as are shown in the data presented. We are justified in accepting the explanation to be fluctuations in the natural abundance of the various size-classes. Variation in the activity of natural enemies might explain such fluctuations, but the cause is more likely to be found in the relative number of eggs spawned and successfully hatched each year during the preceding few years.

The outstanding feature of the data here presented is the fact that one dominant size-class does appear in the catch and may be observed through three successive years continuing to dominate the other classes. The fish comprising this abundant class appear each following year as a larger size due to annual growth. The relative scarcity of certain sizes also recurs year after year in the same regular annual size progression through the four years.

CALIFORNIA FISH AND GAME COMMISSION FISH BULLETINS

- *No. 1. Report on Fish Conditions; 1913; 48 pp., 3 figs. Contains:
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- I. Thompson, Will F. The California Sardine and the Study of the Available Supply, pp. 5-66, 18 figs., 3 tables.
 - II. Sette, Oscar Elton. Sampling the California Sardine: A Study of the Adequacy of Various Systems at Monterey, pp. 67-124, 10 figs., 10 tables.
 - III. Higgins, Elmer H. A Study of Fluctuations in the Sardine Fishery at San Pedro, pp. 125-158, 18 figs.
 - IV. Thompson, Will F. Errors in the Method of Sampling Used in the Study of the California Sardine, pp. 159-190, 13 figs.
 - V. Scofield, W. L. The Sardine at Monterey: Dominant Size-classes and their Progression, 1919-1923, pp. 191-222, 15 figs.

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